REED'S ENGINEERING

FOR

Masters, Mates

AND

JUNIOR ENGINEERS

BY

HERBERT H. R. DAISH,
JOHN FORREST,
JOSEPH H. SWORD,
AND
WILLIAM EMBLETON
(*Extra First Class Engineers*)

Printed and Published by
THOMAS REED & CO., LTD.
184 HIGH STREET WEST, SUNDERLAND.

CONTENTS

LIST OF ILLUSTRATIONS.

INDEX

Reed's Engineering for Masters, Mates and Junior Engineers

CHAPTER I.

METALS USED IN ENGINEERING.

DUCTILITY is the property of a metal which allows it to flow in the direction of its length, when subjected to lateral pressure. In the operation of making wire, called " wiredrawing," the material is pulled in tension through holes which are successively smaller. The material of the wire, under the side pressure exerted by the hole in the die plate, gets smaller in diameter, but greatly increases its length. A soft and very ductile material is needed for this operation.

MALLEABILITY is the property which enables a metal to be worked, by hammering or rolling, into new shapes. Metals which spread in all directions under hammer action, decreasing in thickness and increasing in area without cracking or breaking, are malleable.

Gold possesses this property in the highest degree, for it may be beaten out into a very thin form called gold leaf.

HARDNESS is the property by which a metal resists cutting or penetration.

BRITTLENESS is the property possessed by metals which break asunder into pieces when subjected to shock.

STRESS is the resistence set up in the material to the action of external loads, and is expressed per square inch of section, or as $\frac{\text{load}}{\text{area}}$

STRAIN is the deformation or change of form due to the loading and is expressed per inch of length, or

$$\text{Strain} = \frac{\text{extension}}{\text{original length}}$$

MODULUS OF ELASTICITY (E), is the ratio of stress to strain ; this ratio is constant within the elastic limit.

$$E = \frac{\text{stress}}{\text{strain}}$$

FERRUM OR IRON is an element. Iron ore is a compound of iron and oxygen ; or of iron, carbon and oxygen, associated with earthy matter.

CAST IRON is an alloy of iron and carbon, with small quantities of silicon, phosphorus, sulphur and manganese present. In the blast furnace, the iron is separated from the earthy matter of the ore. The metal which is tapped in the molten form from the furnace contains about 3½ per cent. of carbon, and is generally called Pig Iron.

PHYSICAL PROPERTIES OF CAST IRON. The ultimate tensile strength of cast iron is from 8 to 10 tons per square inch. Its ultimate compressive strength is from 40 to 45 tons per square inch. It is therefore weak in tension and strong in compression. When a piece of cast iron is broken in tension, its fracture shows a greyish crystalline structure. Of the total carbon present, part only is in chemical combination ; the remainder of the carbon is dispersed throughout the metal in the form of minute graphite flakes, visible to the eye.

Soft cast irons have up to about 0·2 per cent. of carbon in combination, and the fracture is dark grey, showing large crystals. When the combined carbon is 0·5 per cent., the fracture is grey, but the crystals are smaller, the metal is closer grained and stronger. Castings for ordinary work which have to be machined contain from 0·2 to 0·5 per cent. of combined carbon. Cast iron being very fluid when melted, may be run into any form of intricate mould ; and parts of machines which are difficult to forge may be made of it, provided that the necessary strength can be obtained. It can be easily machined, drilled and filed. It has no ductility, and its form cannot be altered by bending or hammering, either in the cold condition or when hot. It is a brittle material, and when tested to destruction, breaks without elongation, or reduction of area. It cannot be hand-welded. Not all the cast iron produced is used for castings. Much of it is used for conversion into wrought iron and steel, for the product of the blast furnace is the raw material from which all wrought irons and steels derive their principal ingredient—ferrum or pure iron. Special cast irons, called Semi-Steels, are made by adding from 15 per cent. to 25 per cent. of scrap steel to ordinary cast iron. By this means the tensile strength may be increased to about 16 tons per square inch The specific gravity of cast iron is 7·2. It is used for engine bedplates, columns, cylinders, pistons, slide valves, valve chests, hawser pipes, bollards, stern tubes, propellers, etc.

WROUGHT IRON. When most of the carbon has been taken from cast iron by a special process, the material remaining is called wrought iron. It is almost pure iron, and contains very small traces of carbon. It is often spoken of merely as iron.

PHYSICAL PROPERTIES. Wrought iron is malleable, ductile and strong. Its ultimate tensile strength is about 22 tons per square inch, and its ultimate strength in compression is about the same. It is fibrous in structure, and may be easily forged and

welded. It can be cut and worked readily by machine and hand tools. It was formerly used for plates for ship hulls and for boilers, for shafting, rods and other parts of engines. These various parts are now made largely of mild steel, which has displaced wrought iron as a structural material. Iron rivets are still frequently used in ship construction. It is said to corrode less rapidly than mild steel.

MILD STEEL is an alloy of iron, carbon and manganese. Ordinary mild steel contains about 0·2 per cent. of carbon, and about 0·5 per cent. of manganese.

PHYSICAL PROPERTIES. The ultimate tensile strength of mild steel is from 28 to 32 tons per square inch, and its ultimate strength in compression is about the same. It is therefore stronger than wrought iron. It is malleable and ductile, and more regular in structure than wrought iron. Its fracture exhibits a soft grey, closely-grained crystalline formation. It may be forged and welded by hand, but it does not weld so easily as wrought iron. It is easily machined and cut. The strength of mild steel varies with the contents of combined carbon; as the strength increases, however, the ductility decreases, and the steel is not so easily worked. Very soft, ductile mild steels may contain as little as 0·13 per cent. of carbon, with a strength of 26 to 30 tons per square inch; stronger and less ductile mild steel may contain upwards of 0·3 per cent. of carbon, with tensile strength from 28 to 36 tons per square inch. It follows that plates which have to be flanged or worked in the fire, and which are made of soft ductile steel, will have a range of strength from 26 to 30 tons per square inch; while plates which are worked into forms and shapes which require less arduous treatment, say merely cold rolling, may be made of steels having a range of strength from 28 to 32 tons per square inch. The important point to note here is that for plates which have to be flanged and worked hot, ductile steel of low carbon content must be used, and a little strength is sacrificed to gain ductility, which means ease in working. The addition of from 2 to 3 per cent. of nickel to ordinary mild steel has the effect of strengthening the steel and slightly increasing the ductility, but the cost of the steel is greatly increased. Mild steel is used for the frame work and the shells of ships, for all parts of modern marine boilers, for shafts, rods, steam pipes and parts of engine frames.

STEEL CASTINGS. Steel is used for casting parts which require to be strong in tension, and which may have to resist shock; it is in these essentials that cast iron is weak. Though steel is not so easily cast into moulded parts as cast iron, yet by modern methods good steel castings, strong and reliable, are made. Parts difficult to forge, which are required to have the properties of forgings, and which otherwise might have to be cut from solid masses of material, are cast of steel. Steel castings are in many cases annealed to relieve internal stresses caused by the various parts cooling at different rates.

Ordinary steel castings are of mild steel with from 0·2 to 0·3 per cent. of carbon, and their tensile strength is about 28 tons per square inch in tension. Cast steel of this kind is sometimes used for stern frames, stem posts, rudder posts, rudder quadrants and tillers in ships ; and for the shells of main bearings and bottom end or crank pin bearings, for brackets, for stop valve bodies, and sometimes for engine bedplates.

HIGH CARBON STEEL. When steel contains more than 0·3 per cent. of carbon, it may be hardened by being first raised to red heat then quenched in water. If the steel is to sustain a cutting edge, however, its carbon contents will require to be not less than about 0·5 per cent. This tool steel is often called high carbon steel, to distinguish it from mild steel. For making springs, the steel contains about 0·5 per cent. of carbon. For making cutting tools, the carbon varies from about 0·7 to 1·0 per cent.

PHYSICAL PROPERTIES. These high carbon steels are stronger than mild steel, their strength in tension being from about 40 to 60 tons per square inch, with a carbon range of from 0·7 to 1·0 per cent. These steels have little ductility, are difficult to work hot, and cannot be worked cold except by cutting, and then only with difficulty.

When made red hot and quenched out in water, they may become extremely hard and brittle. The usual method of tempering these steels to sustain a cutting edge, is to first heat them to red heat, quench in water, then reheat slowly until the desired colour is observed on the surface of the tool. For as the steel is reheated after quenching, a succession of different colours flows over the surface, and each colour is associated with a certain hardness. When the desired colour, and therefore the desired hardness is achieved, the tool is at once quenched out again in water, and the tempering operation is ended.

TESTING OF MATERIALS. Steel and iron which is used in the construction of ships and boilers is required to be of specified strength and ductility. All the metals used in engineering have elasticity, i.e., they have the ability to return to their original size and shape after the load has been removed ; but there is a limit to their recovery of form. The " elastic limit " is the stress beyond which the material has no power of recovery. All metals in ship and engine parts endure stresses much below the elastic limit. A specimen of the material to be tested has a tensile pull exerted on it by a special machine, which is capable of imposing any desired load on the specimen. Within the elastic limit, the stretching or elongating of the specimen is too small to be visible to the naked eye, but with accurate measuring instruments it can be ascertained that the extension is proportional to the load. After the elastic limit is reached, the material has lost its elasticity, and the extension increases at a greater rate than the load, and the stretching of the

specimen is visible. The material is now in a plastic state. After a certain elongation is exceeded, depending on the ductility of the material, the specimen breaks. The greatest load which the machine exerted on the specimen, divided by the original area, gives the ultimate stress. The several parts of the specimen are pressed together by hand, the final length is measured, and the total elongation determined.

$$\text{Elongation per cent.} = \frac{\text{Final length} - \text{Original length}}{\text{Original length}} \times 100$$

Just before breaking, the specimen thins down where rupture is about to occur, and the reduction in area at this part is also a measure of the ductility.

$$\text{Reduction in area per cent.} = \frac{\text{Original Area} - \text{Final Area}}{\text{Original Area}} \times 100$$

TESTS FOR PLATES AND RIVETS. The Board of Trade require that mild steel for boilers shall have an ultimate tensile strength of from 28 to 35 tons per square inch, with an elongation of 20 per cent. in a specimen originally 8 inches long between gauge points; this is the steel used for boiler shells, stays, etc., and for parts which do not have to be flanged or worked hot.

For plates which have to be flanged, the steel must have an ultimate strength of from 26 to 30 tons per square inch, with an elongation of 23 per cent. on the 8 inch specimen. The range of stress is to be not more than 4 tons per square inch, i.e., 26 to 30 for plates to be flanged; 28 to 32, or 29 to 33, or 31 to 35 tons per square inch in the case of shell plates. The tensile strength of bars from which rivets are made is to be from 26 to 30 tons per square inch, with an elongation of 25 per cent. on the 8 inch specimen.

The rivet shanks are to be bent cold through 180 degrees, by hammering, until the two parts of the shank touch without fracture on the outside of the bend; the rivet heads are to be flattened, whilst hot, without cracking at the edges, until their diameter is $2\frac{1}{2}$ times the diameter of the shank.

In the case of steel castings, the tensile strength should be from 26 to 35 tons per square inch, with 20 per cent. elongation on an 8 inch specimen. Test pieces cut to a rectangular section 1 inch by $\frac{3}{4}$ inch, with the edges slightly rounded, are to be bent cold through an angle of 120 degrees without fracture. Stern frames of cast steel are to be let fall on hard ground after being held at an angle of 45 degrees, excavations being made to take bosses and other projecting parts. After this percussion test, the casting is to be well hammered with a 7 lb. hammer to satisfy the surveyor that it is free from flaws.

ANNEALING. When plates and bars are heated for flanging or forging, the material is severely punished in places, and serious

internal stresses are induced. To relieve these local stresses the plates are annealed. The plates are put into a furnace, the temperature is slowly raised to about 1400° F., maintained constant for a while to make sure that the heating is uniform, then the plates are allowed to cool slowly.

Every part of each plate must have the same temperature, and all must cool down slowly and regularly. When the plates have cooled down, the internal stresses have been removed or greatly reduced, and the plates are said to have been annealed. Chains must be periodically annealed. Due to suddenly applied loads in the nature of shock, and to repeated variation of stress, they are said to become fatigued ; that is the cohesion between the molecules is partly destroyed. The original strength may be restored by resting the chains for fairly long periods, or by annealing. They are annealed by heating to the required temperature in a furnace, or sometimes merely in a smith's fire, then allowed to cool as slowly as possible.

NORMALISING is another process used for bringing steel back to its initial condition after flanging or working hot. The plates are put into a furnace, raised to about 1400° F., kept at that temperature for about 4 hours, then allowed to cool in the open air.

MALLEABLE CASTINGS. The brittleness of cast iron may be removed, in the case of small castings, by a special process. The parts to be treated are put into iron boxes, and entirely covered with powered red hematite (a pure iron ore) ; the boxes are then put into a furnace and heated to a bright red. This heat is maintained for several days, when the boxes are removed and allowed to cool slowly. The small parts taken out of the boxes are now malleable, and will endure a reasonable amount of hammer action.

DROP FORGING or stamping is used when a great number of similar parts of limited size is needed. Two dies are used. Into each die is cut, in relief, the form of that part of the forging which will ultimately fill it. One die, containing the impression of one half of the forging, is fastened to the head of the steam hammer. The other die containing the impression of the other half of the forging is fastened on the anvil. A billet of steel, of the correct weight, is put on the lower die, and the operation is completed by pressing and hammering the dies together.

NON-FERROUS METALS.

COPPER is used in its pure state for parts which are exposed to fresh and salt water. Fresh water has practically no action upon this metal, and it resists fairly well the corrosive action of sea water. Copper is very malleable, being easily hammered or beaten out into thinner forms. It is ductile and may be forged hot or in the cold state. It conducts heat rapidly, and is one of the best known conductors of electricity. It is used extensively in the form of wire,

both for electrical and mechanical purposes. Copper is worked into plates and thin sheets ; it is used for pipes to carry steam and water. It is an important element in alloys such as brass and bronze. Its tensile strength is about 9 tons per square inch in tension, but if it is annealed its tensile strength may be increased to about 12 tons per square inch. This metal is annealed by being raised to a dull red heat, then quenched out in water ; it is then very soft and pliant. Copper loses strength rapidly with increase of temperature, and this is one reason why it is not suitable for pipes which may carry superheated steam.

ZINC is used in the form of thin plates for making small articles. It is used in galvanizing to coat the surfaces of plates and other objects. It is almost unaffected by exposure to water. Zinc alloys with copper to form brass, and this is one of its principal uses. It is electro-positive to all other common metals, and for this reason is used to prevent corrosion of steel plates in boilers. It is a weak metal, having a tensile strength of from 1 to about 4 tons per square inch.

LEAD is used mostly in the form of sheets and for pipes. It has little tensile strength, generally less than one ton per square inch. It is malleable and ductile. It is used for bends in pipe lines carrying water, as it will yield easily under stress. It is extensively used in houses for carrying water. It resists the acid action of bilge water, and is sometimes used for bilge pipes. A small quantity of lead is sometimes used in brass alloys. Its melting point is about 620° F.

TIN is much used for coating the surfaces of thin iron plates, and as an element in bronze. It is malleable and ductile, with a low tensile strength of about 2 tons per square inch. Water has no action on pure tin, and it withstands the acid action of fruits, etc. Ordinary tinned plate consists of thin iron sheet coated with tin. Tinfoil is pure tin rolled into very thin sheets.

BRASS is an alloy of copper and zinc. Ordinary cast brass contains about 66 per cent. of copper and 33 per cent. of zinc. The tensile strength is about 10 tons per square inch, and may be greatly increased by annealing. Rolling and working, as in the case of rods, increases the strength, and a brass of the given proportions of copper and zinc, may with suitable working, have a strength of 22 tons per square inch. Cast brass has very little ductility, and will if hammered or beaten soon develop cracks. Cast brass is used for sea cocks, pump barrels and liners, valves, valve seats, boiler mountings, etc.

MUNTZ METAL is a special brass containing 60 per cent. copper and 40 per cent. zinc. It is strong, having a tensile strength of about 24 tons per square inch. It is ductile and malleable and may be forged hot or cold. It is used for pump rods, bolts and studs,

valve spindles, and any parts which must have strength in combination with the property of resisting the corroding action of fresh and sea water.

DELTA METAL is an alloy of copper, zinc and iron, the contents of iron being up to 2 per cent. The tensile strength may be as high as 40 tons per square inch. It may be cast and rolled, and may be used instead of muntz metal for pump rods, etc., having the same non-corrosive qualities. Propellers are sometimes cast of this material.

It should be explained that every different alloy of copper and zinc will have a different strength and ductility, and small changes in composition often greatly alter the properties of the alloy.

BRONZE is an alloy of copper and tin. The proportions of copper and tin vary greatly in different bronzes. Gun metal is a bronze containing 90 per cent. copper and 10 per cent. tin. Its tensile strength is about 15 tons per square inch, and it is strong in compression, It has little ductility, but it is not affected by sea water. It is hard, and wears slowly when used for the bearings of machines and small engines. It is often used for boiler mountings, and for parts which have to be exposed to sea water. When used for bearings, a small amount of lead is added, and a commonly used bronze for bearings contains about 87 per cent. copper, 11 per cent. tin, and 2 per cent. lead.

MANGANESE BRONZE is an alloy of copper, zinc, iron and manganese, the proportions of which may vary greatly. It is hard and strong, and often used for propellers, when its composition may be 64 per cent. copper, 34 per cent. zinc, 1 per cent. iron and 1 per cent. manganese, with a tensile strength of about 28 tons per square inch. It has only slight ductility.

MONEL METAL is an alloy of copper and nickel, containing about 75 per cent. copper and 25 per cent, nickel. It is very strong, its tensile strength being upwards of 40 tons per square inch, it can be worked hot or cold, and is non-corrosive to most acids. It is used for pump rods, and sometimes for valves and seats in stop valves carrying superheated steam. An alloy of this kind, having about 70 per cent. copper, and 30 per cent. nickel is now being used for condenser tubes.

WHITE METAL is an alloy with a low co-efficient of friction, used for lining the bearings of shafts, thrust collars, guide shoes, etc. Its composition may vary widely. One kind, called Babbit's metal, contains 84 per cent. of tin, 8 per cent. of copper and 8 per cent. of antimony. Some of the cheaper white metals contain lead, and are liable to " spread " under the blows which sometimes come on the bearings. These metals are plastic, but they wear slowly. Very slight wear is imposed by white metal on the shaft ; and the shell of the bearing can easily be taken out of its place and the

wearing surface of white metal renewed. Its melting point is somewhat low, about 660° F., and care must be taken to keep the bearing cool. White metal is used in compression only.

CASE HARDENING. Parts made of wrought iron and mild steel are sometimes required to be surface hardened to resist wear. The parts to be treated are packed in boxes with some material rich in carbon, such as scrap leather or charcoal. The boxes are made air tight, then placed in a furnace and heated to a bright red heat. Some of the carbon is absorbed by the iron or steel parts, and the surfaces are converted into a sort of high carbon steel. The parts are then quenched out in water, and the surfaces are thus hardened. It should be noted that the surfaces only are altered by this treatment, the internal portion of the material remaining unchanged.

WELDING is the process of uniting two pieces of metal by first heating them to a white heat (about 1500° F.), then hammering them together. The parts which are to be joined together must first be tapered or scarfed, and the longer the scarf is made the stronger will be the weld. After scarfing, the parts are both made white hot. Before uniting, sand or borax is lightly sprinkled across the surfaces. The two parts are then hammered together. The sand or borax used is called a " flux," and its function is to prevent oxides of iron forming on the surfaces, as these oxides prevent good cohesion of the two parts. Wrought iron and mild steel weld readily by this process, which is generally carried out on the smith's anvil or under a steam hammer.

OXY ACETYLENE WELDING. The heat generated by the oxy acetylene flame will reduce metals to the molten state. The gases are stored under pressure in separate steel cylinders. Two small pipes, one carrying oxygen, the other carrying acetylene gas, converge at an angle so that the two gases mix, and combustion takes place upon applying a flame. This arrangement is called a blowpipe. In welding two pieces together, the parts, which may be scarfed or merely butted, are first cleaned, then arranged about $\frac{3}{16}$ inch apart. The flame from the blow lamp is directed upon the two surfaces until they are white hot, and at the same time a rod of Swedish iron of small diameter is held in the flame. The molten metal from the rod drops on to the surfaces to be united, which should also be in the molten state, and the parts are welded together. This method of welding is sometimes used to repair cracks in the internal parts of boilers (parts which are in compression only).

OXYGEN JET FOR CUTTING. Plates may be cut through by means of the oxygen jet. The oxy acetylene flame is used to make a small area of the plate red hot, then a stream or jet of oxygen acting alone is directed into the heated part. The material of the plate is burnt away by the rapid combination of the metal and the oxygen, a saw-like cut being burnt through the plate.

ELECTRIC WELDING. If an electric circuit be broken, and the gap which is made be gradually increased, the current continues to flow across the air space in the form of an arc, generating intense heat. One terminal from a dynamo is connected to the plate to be welded, the other terminal is connected to a rod of Swedish iron or mild steel of small section by an insulated handle held in the operator's hand. The process is started by touching the plate with the rod ; this completes the circuit and the current flows. As the rod is slowly moved from the plate the arc is formed, the final distance across the arc being roughly $\frac{1}{8}$ inch. The heat developed by the arc is sufficient to raise the surfaces to be welded to the correct heat. The molten metal passes in drops from the end of the rod, flows in between the two surfaces to be welded, and unites them. This is a convenient method of welding up cracks in the internal parts of boilers, such as the heating surfaces, which are subject to compressive stresses only. The crack is cut out by a chisel which makes a slot in the plate about $\frac{3}{16}$ inch wide, if necessary right through the plate, then the new metal is built up from the bottom of the slot until it is completely filled. All parts must be perfectly clean. In this process the heat developed depends upon the value of the current of electricity, and the dynamo used gives a low voltage, say about 50 volts, and a large current.

MATERIAL.	Ultimate Strength. Tons sq. inch.		Elongation %.	Weight per Cubic foot lb.
	Tension.	Compression.		
Cast Iron	9	40	Nil	450
Wrt. Iron	22	22	about 20% in 8 ins.	480
Mild Steel	28	28	20% in 8 ins.	490
Cast Brass	10	6		about 510
Rolled Brass	20			
Copper	9			550
Bronze	15			about 540

It should be noted that the ultimate strength of alloys depends upon the proportion of the ingredients.

Factor of Safety is the ratio $\frac{\text{Ultimate Stress}}{\text{Working Stress}}$

CHAPTER II.

MARINE BOILERS

There are two types of steam boilers used in marine practice. In the first type, the boiler consists of a cylindrical shell which contains the furnace or furnaces in which the fuel is burned. The heating system, which consists of furnaces, combustion chambers and a great number of tubes from about 2·5 to 3 inches diameter, is contained within the boiler shell, and is entirely surrounded by, and is in contact with the water. The cylindrical shell generally lies horizontally, but in the case of boilers of small output it may be set vertically. The furnace gases and smoke pass from the furnace to the combustion chamber, where combustion is practically completed ; the hot gases then pass through the tubes, which leave the combustion chamber at some height above the furnace. Through the tubes, the gases are conducted to the smoke box, outside the boiler, which leads to the funnel. This type is called the **CYLINDRICAL MULTITUBULAR BOILER,** and it is the type in common use in the Merchant service for the main propelling machinery. For main boilers of this type, with the cylindrical shells horizontal, the diameter may be as great as 17 feet, and in the case of single ended boilers the length may be up to about 12 feet. For double ended boilers of this type, the length may be up to 22 feet. The single ended boiler may have from 1 to 4 furnaces, which enter the boiler from one of its ends only. The double ended boiler has furnaces projecting into it from both of its ends, and may have from 2 to 4 furnaces in each end, a total of from 4 to 8 furnaces.

For auxiliary purposes in port, one of the main boilers may be used, or if a comparatively small output of power is needed, a smaller boiler of similar design may be provided, or a vertical multitubular boiler may be installed. The auxiliary boilers are often called " donkey boilers."

The range of pressure for main boilers of this type is from about 180 to 250 lb. per square inch ; the pressure most often used is from 180 to 220 lb. per square inch.

In the second type, the boiler consists of a great number of tubes from about 1½ inches to 4 inches diameter, through which the water circulates, the furnace gases passing round the outside of the tubes. The tubes may be in straight lengths or they may be curved. One end of each tube passes through the shell of a cylinder called the " steam drum," the other end passes through the shell of a cylinder called the " water drum." Thus the small tubes are connected together by means of these drums. This type is called

THE WATER TUBE BOILER, and it is used for the highest pressures on account of the great strength of its parts, it is also suitable for the rapid raising of steam.

DESCRIPTION OF MAIN BOILER OF CYLINDRICAL MULTITUBULAR TYPE. This boiler is sometimes called the Scotch boiler.

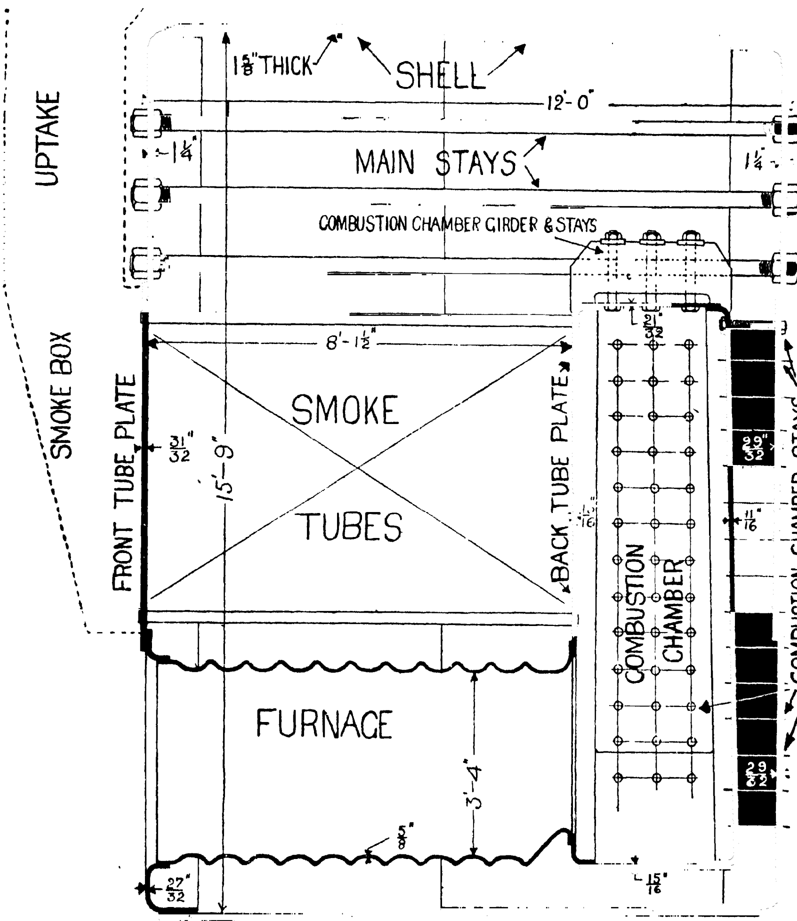


Fig. 1. Longitudinal Section of a Multitubular Marine Boiler.

THE SHELLS of all cylindrical boilers are made of mild steel, of from 28 to 35 tons tensile strength. The plates are cold rolled into the curved form, and jointed together by means of a double

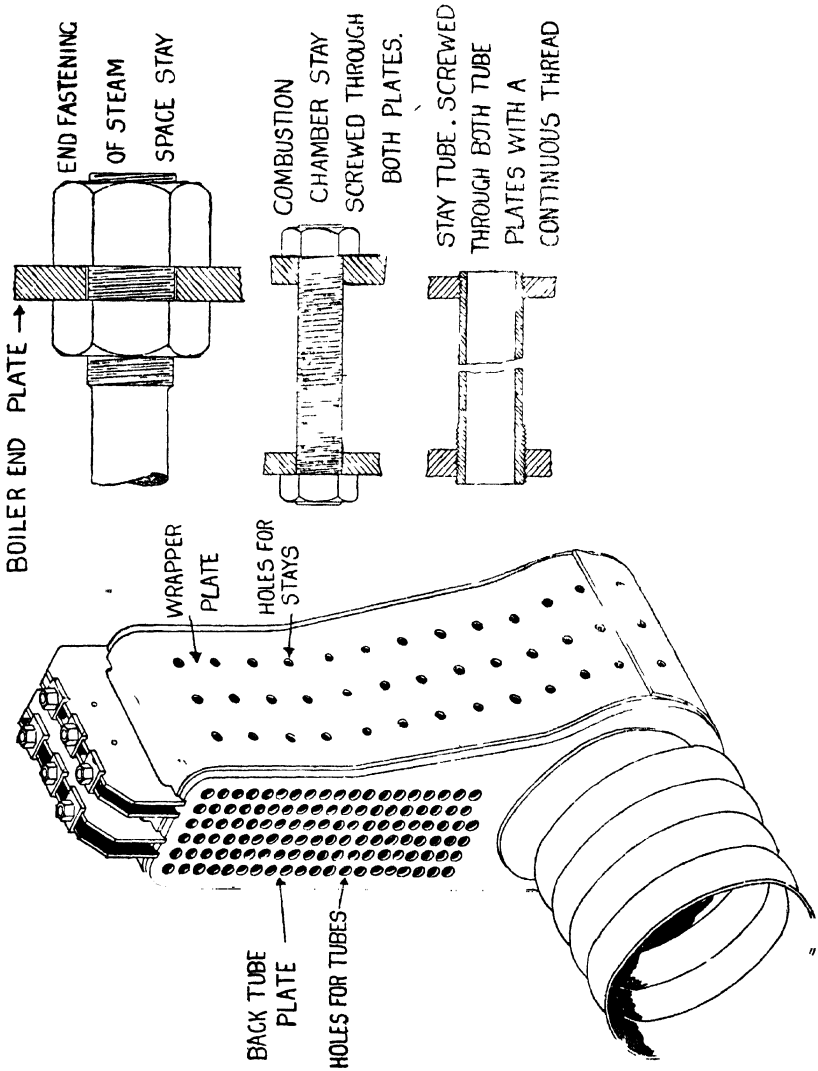


Fig. 2. Combustion Chamber.

butt strap joint. After rolling, the plates are assembled, and the rivet holes are drilled through the two thicknesses in one operation. The plates are then taken adrift, and the edges taken off the holes on the sides where the plates touch ; this assures that the plates make perfect contact, which is necessary for steam tightness. The shell plates are in tension, and as welding is not allowed on parts in tension, shell plates must not be welded. The rivets used must not be less in diameter than the thickness of the plate. The riveting is done by hydraulic machines or by hand. The shell plates do not require staying, as circular parts are self-staying. A working stress of about 7 tons per square inch is allowed in boiler shells.

THE END PLATES are flat surfaces. The boiler ends may be in 2 or 3 horizontal strakes, riveted together by double riveted joints. The end plates are flanged hot, and the flange fits inside the shell to which it is connected by double riveting. All flat surfaces in boilers require staying. The staying divides the flat surfaces into smaller areas, more capable of resisting the pressure.

FURNACES are tubes, generally corrugated, from about 36 inches to 48 inches inside diameter, and from about $\frac{1}{2}$ inch to $\frac{13}{16}$ inch thick. They are of mild steel, of from 26 to 30 tons tensile strength, and are rolled and worked into shape while hot. Their corrugated form makes them stronger to resist the external pressure acting on them, than if they were merely plain tubes, and allows them to yield somewhat in a longitudinal direction without undue stress, as they tend to lengthen by expansion due to heat. The back ends of the furnaces are attached by flanges to the

COMBUSTION CHAMBERS, which are box-like structures roughly rectangular in plan. Each furnace has its own combustion chamber. There are 5 flat plates in the combustion chamber which require staying ; the top plate, the back plate, the two side plates, and the tube plate. The top and the two side plates are one long plate, bent into the correct form, called the wrapper plate. The combustion chamber bottom plate is always rolled into the form of a semi-circular arc, and does not need staying. The combustion chamber plates are from $\frac{1}{2}$ to $\frac{13}{16}$ inch thick—the bottom plate is often made slightly thicker, as it is more liable to corrosion.

SMOKE TUBES are generally of lap welded wrought iron, from 2·5 to 3 inches diameter, about $\frac{3}{16}$ inch thick and 7 to 8 feet long. Sometimes solid drawn steel tubes are used. These tubes are swelled out to a larger diameter at the front end for a few inches of their length, and the holes in the front tube plate are larger than the holes in the back tube plate. This facilitates the fitting of the tubes, which are put in from the front end of the boiler. The tube ends are a good fit in the holes in the tube plates, and after fitting into place, the tubes are tightly expanded into the tube plates by a tool called a tube expander.

THE FRONT TUBE PLATE is the part of the boiler front end plate through which the tubes pass. It is a flat plate about $\frac{7}{8}$ to $1\frac{1}{8}$ inches thick.

THE BACK TUBE PLATE has already been mentioned. It is the tube plate in the combustion chamber, and is from $\frac{3}{4}$ to $\frac{7}{8}$ inch thick. The two tube plates are parallel, they are flat surfaces and must be stayed.

THE BOTTOM PLATE of the boiler front end is flanged to go inside the shell, it is flanged to take the furnace mouths, and flanged inwards to form manholes. **THE MANHOLES** are oval, about 12 inches by 16 inches. A manhole door is entered with its shorter diameter placed along the larger diameter of the hole, pushed completely inside the boiler, then turned round and pulled up into position by hand, by means of the two large studs screwed into the door. The door is held in its place by the studs which pass through dogs or bridge pieces outside the boiler.

THE STAYING OF FLAT SURFACES. The plates of the heating surfaces do not exceed $\frac{13}{16}$ inch in thickness; if the thickness exceeds this value, the plates cannot transfer the heat to the water quickly enough, they become overheated and cannot resist the pressure. The comparatively thin plates of the combustion chamber need stays pitched fairly close together; the stays are from $1\frac{1}{4}$ to 2 inches diameter, the pitch is from about 7 to 9 inches. The stays are screwed through both plates by means of a continuous thread, and thin nuts are fitted on the outside of the plates.

THE MAIN STEAM SPACE STAYS support the top end plates of the boiler. They are up to 3·5 inches diameter, pitched from about 14 to 18 inches apart. The top end plates are not heating surfaces, they can therefore be made thicker than combustion chamber plates. As it is necessary to move about in the steam space of a boiler when cleaning it, the spacing of the stays must not be too close. Top end plates may be as thick as $1\frac{1}{2}$ inches, and the stays are not screwed into them, but pass through and are secured by nuts on each side of the plates. See sketches on pages 12 and 13.

STAY TUBES are tubes of heavier section than the ordinary smoke tubes, and their function is to support the tube plates. Stay tubes are larger in diameter at the front end, and the two ends are cut with a continuous thread. A long tap cuts a continuous thread through the two tube plates, and the stay tubes are then screwed in from the front end. See sketch on page 13.

THE COMBUSTION CHAMBER GIRDERS support the top plates of the combustion chamber. These girders or "dogs" transfer the load on the top plate which lies horizontally, to the back tube plate and the combustion chamber back plate which are vertical. See sketch on page 13.

CAULKING. All riveted seams in boilers are caulked. It is the operation of burring up the edge of the plate to ensure steam and water tightness. If the plates are pulled closely together by the riveting, the caulking should be a precaution and not a necessity.

The caulking tool is used in conjunction with a hand hammer, and the hammer should be used with a moderate force only. Should the caulking tool be driven in by heavy blows, it is apt to wedge apart the plates, causing leakage.

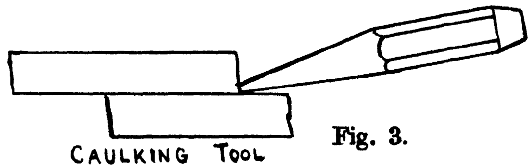


Fig. 3.

The combustion chamber plates are caulked round the screwed stays.

RIVETING. The shell plates are jointed together by a double butt strapped joint of special design. This joint is often called the main longitudinal seam, and its strength is generally about 85 per cent. of the solid plate. The end plates are riveted to the shell by a double riveted joint, the strength of which is about 50 per cent.; this strength is ample, as the boiler is twice as strong circumferentially as it is longitudinally. The joints of the plates of the heating surfaces are single riveted, the rivets being about $\frac{7}{8}$ inch diameter pitched about $2\frac{1}{8}$ inches apart.

THE AUXILIARY OR DONKEY BOILER. A sectional elevation is shown of a vertical multitubular boiler of the well-known Cochran type. The furnace F, and the dome of the shell E, are hemispherical in shape; this shape gives the maximum strength. The furnace is in one piece. A useful size has a diameter over the shell of about 6·5 feet, the height being about 14·5 feet. This boiler would contain about 165 tubes 2·5 inches outside diameter, and the working pressure would be up to 120 lb. per square inch. The hot gases and smoke pass from the

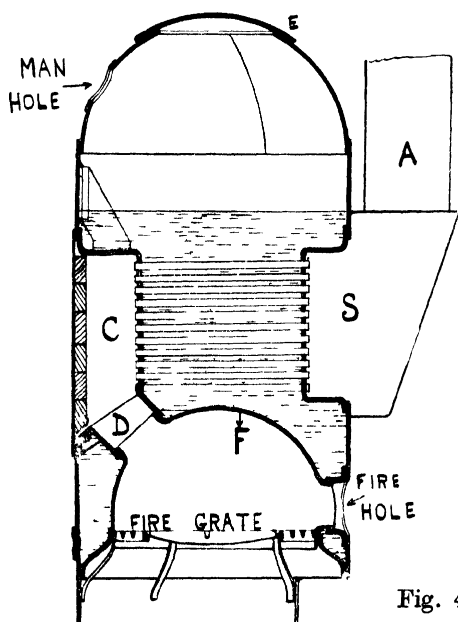
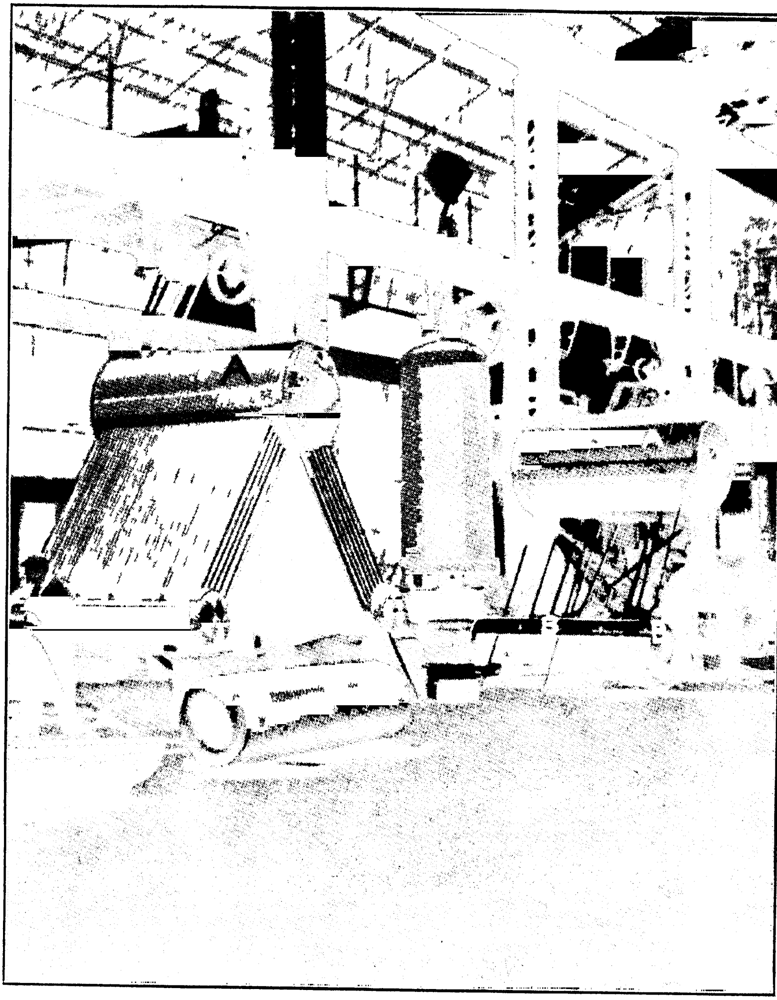


Fig. 4. COCHRANE AUXILIARY BOILER.



[*To face page* 17]

Fig 5

furnace F, through the flue D, into the combustion chamber C; from the combustion chamber the gases pass through the tubes, which provide about $\frac{4}{5}$ of the total heating surface; and from the tubes the gases pass into the smoke box S, and finally into the funnel. This boiler is used extensively in both steam and motor vessels; for auxiliary purposes in port in the case of steam vessels, and for auxiliary purposes both at sea and in port in the case of many motor vessels.

WATER TUBE BOILERS.

YARROW TYPE. The Yarrow water tube boiler consists of three or more cylindrical drums arranged horizontally. The lower or water drums, of which there may be two or three, are connected to a single steam drum by straight tubes of small section, varying from about $1\frac{1}{4}$ inches to $1\frac{3}{4}$ inches diameter, which provide the heating surface. In Fig. 5, which is reproduced from a photograph kindly supplied by Messrs. Yarrow & Co. Ltd., A is the steam drum, B are the water drums, and the straight inclined tubes are seen connecting the steam and water drums. The drums are fitted with ends pressed to a spherical form, this being the strongest form known for resisting pressure, and each drum may be entered by a manhole door in the end plate. The steel plates of the drums are pressed into shape and machined before erecting, and the workmanship is of the highest order. The tubes are of cold solid drawn weldless steel. The firegrate is built in between the water drums, and the triangular space between and including the two nests of tubes, is the combustion chamber. The boiler is completely encased in light steel plates heavily lined with fire brick on the inside, and the funnel may lead either from the end or from the top of the casing. In Fig. 5, the water drums are shown with the lower plates not yet riveted into place. The curved plates of the drum through which the tubes enter are called " tube plates." The tubes are fastened by being tightly expanded into the holes in the tube plates. The end of the steam drum A is shown drilled to take the water gauge cocks, the two feed check valves and the feed water regulator. The only fitting on the water drums is the blow down valve. The steam stop valves and the safety valves are fitted to the shell of the steam drum.

This boiler is suitable for the highest pressures. All its parts are circular in section, and as they are of small diameter have great inherent strength. There are no flat surfaces, and therefore stays are not needed. The circulation of the water is very rapid. The water in the tubes nearest the fire rises into the steam drum, the cooler water in the drum descending through the outer rows of tubes into the water drum, thus a natural circulation is maintained. For efficiency in heating water, one side of the tube should be covered by a rapidly circulating current of water, and the other side by the moving gases; this is because gases and liquids are bad conductors

of heat, and really give up heat by convection. The total amount of water in a boiler of this type is small, the evaporation is rapid, and therefore great care must be taken to ensure a regular supply of feed water. An automatic feed water regulator of special design keeps the water always at the same level. The Yarrow boiler is the type mostly used in naval vessels, and it is also used extensively ashore. The maximum pressure for a cylindrical Scotch boiler is about 300 lb. per square inch ; water tube boilers of the Yarrow type are working at 1,200 lb. per square inch, and higher working pressures may be anticipated.

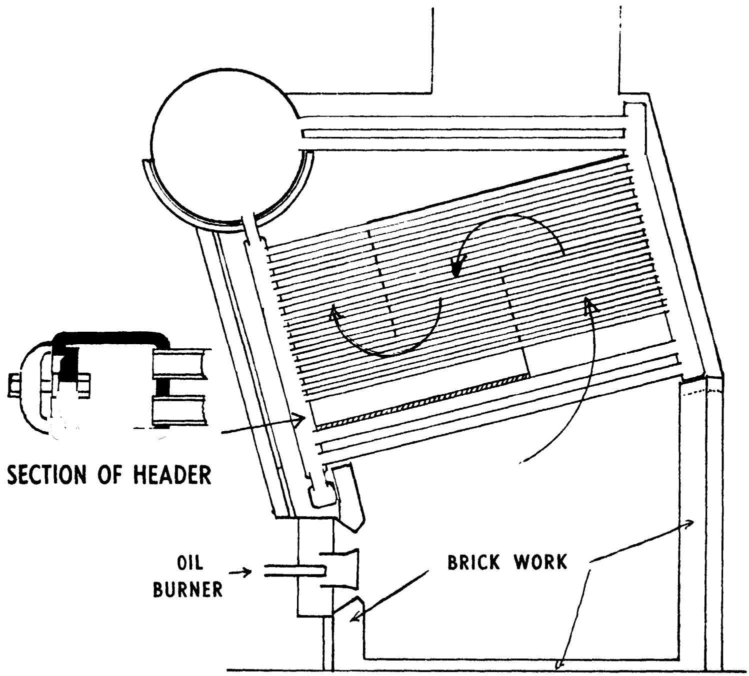


Fig. 6.

Another type of water tube boiler is shown in Fig. 6. In this type there is a steam and water drum suspended from which there are a number of 'headers' . These are of rectangular section and are each joined to the steam and water drum at the top end by short pieces of tube, and to a cross drum of similar section at the bottom by other short tubes. Another row of headers are placed at the back of the boiler and the heating tubes pass from the front to the back headers. There are also two rows of tubes from the top of the back headers to the steam and water drum. The furnace is below the inclined tubes. The whole is enclosed by a light steel casing and the furnace is lined with firebricks.

The advantages claimed for these boilers are :—

The large heating surface exposed to the direct radiation from the fire.

The large furnace and combustion space, giving complete combustion of fuel.

Rapid circulation of the water in all the tubes.

The boiler can be forced without fear of injury

Small space occupied for given output of steam, so that in a vessel of a given size, much greater power can be developed by using water tube boilers.

Further, on account of the small quantity of water in these boilers, and the fine sub-division of the water into so large a number of tubes, should a tube burst there is not the same danger as in the case of the Scotch boiler.

Much less weight for a given power than the Scotch boiler.

The only disadvantages are :—Pure clean feed must be used; feeding and firing must be very regular, the feed water being automatically controlled.

The advantages claimed for the Scotch boiler are :—

On account of the large amount of water it holds, there is more reserve power. It can use less pure feed water with greater immunity from damage. Should the feed supply be cut off, it can be worked for some time with safety.

BOILER MOUNTINGS.

The essential fittings or mountings on a steam boiler are :—

THE SAFETY VALVE. This is a safety device. It is a spring loaded valve, that is, the valve is kept down against the steam pressure by means of a helical spring. The function of the safety valve is to lift or open immediately the pressure inside the boiler exceeds the designed working pressure, and by discharging the steam into the atmosphere through the waste steam pipe, prevent the pressure rising above a definite value. There must be two safety valves fitted to each boiler, and sometimes three are fitted. Under working conditions, with bright fires, and with the engines stopped, the safety valves must be able to discharge the whole of the steam generated; and while the valves are "blown off," the steam pressure must not increase by more than 10 per cent. of the designed or working pressure. Thus in the case of a boiler working at 200 lb. per square inch, if the engines are suddenly stopped and the fires are bright, the safety valves will lift and "blow" immediately, and the pressure must not increase to more

than 220 lb. per square inch. The safety valve is always fitted directly on to the highest part of the shell of the boiler. The body of the casting is made of cast iron, the valve, valve seat and the spindle are made of brass.

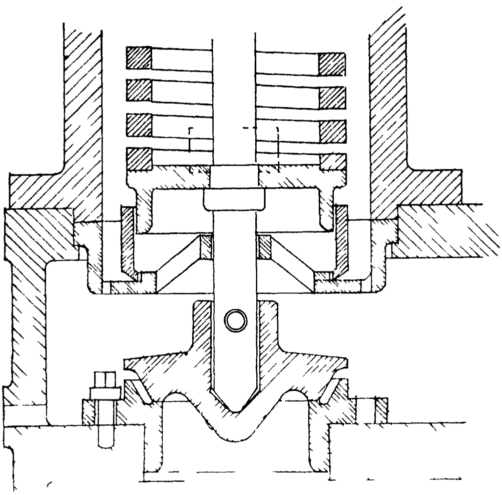


Fig. 7.

A special form of the spring loaded safety valve is shown in Fig. 7. A type of piston is formed on the valve spindle, the area of the piston being larger than the area of the valve. When the pressure in the boiler rises above the proper value, steam escapes from the underside of the valve to the space above it. This space therefore is filled with low pressure steam which, acting on the under side of the piston lifts the valve against the load of the spring further than if the piston was not there. Since the valve lifts a greater amount the area of escape is greater than with the common type of valve and a smaller diameter of valve may be used for the same conditions.

EASING GEAR. An apparatus, called the easing gear, is fitted to the safety valves, by means of which the valves can be lifted from the engine room platform and the boiler pressure rapidly reduced if necessary.

THE WATER GAUGE. This is the important fitting which shows to the observer the position of the water level inside the boiler. As in the case of the safety valve, the water gauge is a safety device, for upon its correct working the safety of the boiler depends. The heating surfaces must always be submerged beneath the water in the boiler when the fires are burning · and should the water level be allowed to fall, by incorrect working of the water gauge, or by incorrect observation of the water gauge, the plates exposed to great heat may become dry. These plates will at once be made red hot, lose their strength, and collapse under the steam pressure. This will cause an explosion, put the boiler completely out of action, and perhaps result in loss of life.

The Water Gauge, in its simplest form, consists of three cocks and a glass tube :—the steam cock B, which puts the glass tube G in connection with the steam space ; the water cock C, which puts the glass tube F in connection with the water in the boiler ; the drain cock D, which is used at frequent intervals to ascertain that cocks B and C are clear or unobstructed. The water cock C is placed, in the case of the cylindrical Scotch boiler so that the water will just be visible in the bottom of the glass tube when the combustion chamber top is covered to a depth of 6 inches. The glass tube or " gauge glass " is about 16 inches long, and the working water level is about " half glass " which means that there is about 8 inches of water showing in the gauge glass. A slight variation only is allowed in the height of the water level, say about 2 inches above and below the level at " half glass." The water gauge is usually fitted to the back end plate of the boiler, but it is obviously better to have a water gauge at each end of the boiler, so that the water level can be correctly observed when the vessel changes trim.

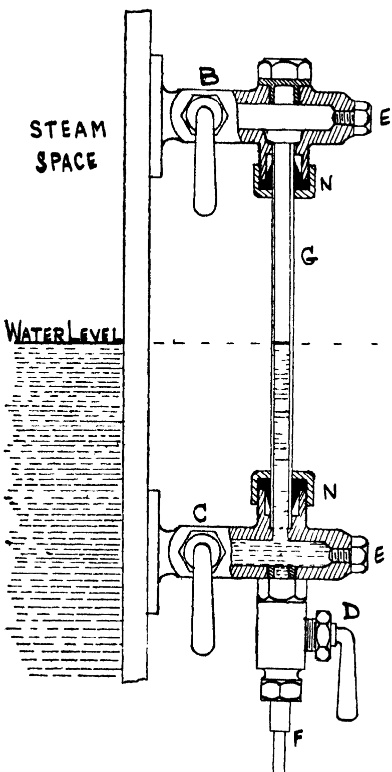


Fig. 8.

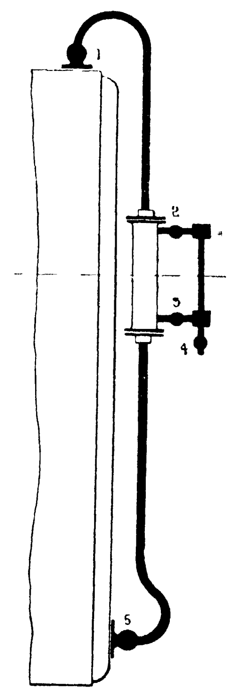


Fig. 9.

In Fig. No. 8, cocks B and C are open, the drain cock D is shut. To test the gauge :—Shut B and open D, then if water is blown out of the drain pipe F, the passage ways in the water cock C are clear. Now shut C and open B, keeping D open, then if steam is blown out of the drain pipe F the passages in the steam cock B are clear. The water gauge requires frequent testing. When the boiler is not under steam, the bolts E may be removed and a wire passed through the passages in the cocks, clearing out any dirt or scale The cocks are always made of brass. The gauge glass is kept from leaking by means of the conical woodite ring and the gland nut N.

Instead of having the gauge cocks fitted directly to the boiler plate as in Fig. 8, a common arrangement is to have them mounted on a hollow column usually made of brass ; the column may be fastened by flanges directly to the boiler plate, or it may be connected to the steam and water spaces by long pipes as shown in Fig. 9. These pipes must be fitted with cocks where they enter the boiler, so that if an accident happens to the pipes, they can be shut off from the boiler. This arrangement is called the " double shut off." The advantage of this system is that in rolling and pitching of the ship, the water level in the gauge glass rises and falls a small amount only, because the water pipe at 5 is always submerged; whereas in Fig. 8, the water level may rise and fall through the whole length of the gauge glass when the ship is rolling, as the entrance to the water cock is near the surface of the water. Fig. 9 is a diagram only.

To test this gauge : Shut cocks 1 and 2, cocks 3, 4 and 5 being open ; if water is blown out of the drain pipe at 4, then the water cocks and 5 are clear. Now shut cocks 3 and 5, open 1 and 2. and if steam is blown out of 4, then the steam cocks 1 and 2 are clear. Suppose that when 3, 4 and 5 are open that no water comes through the drain at 4, it must now be found whether 3 or 5 is choked ; shut 1 and 3, open 5, 2 and 4, then if water is blown from 4, the cock 5 is clear. To determine if 3 is choked, shut 2 and 5, open 1, 3 and 4, then if steam comes through 4, cock 3 is clear. Generally speaking the steam cocks seldom choke up, the water cocks are occasionally liable to have dirt or scale forced into them. All the cocks of the water gauge should be carefully examined in port when the boiler is empty, and all the passages carefully cleaned out. This is a matter of very great importance.

THE PRESSURE GAUGE. This is a gauge which records on a circular dial by means of a pointer, the pressure of steam in the boiler. It is entirely automatic in its action. A small copper pipe about ½ inch diameter is taken from the highest part of the end plate or the shell in the steam space, to the pressure gauge, which is placed at a convenient height for reading. There is a cock fitted to the end of the pipe on the boiler, and to the end which takes the gauge.

TEST COCKS. The regulations provide that there shall be two separate means of testing the water level. Three test cocks are used as shown in Fig. 8; the lowest one should be about 6 inches above the combustion chamber top, the middle one should be at the working level, and the top one about 6 inches above that level. Should serious accident put the water gauge out of action, the test cocks may be used. The lowest one must always discharge water when opened. Should the middle one discharge water when opened, and the top one discharge steam, the water level is about correct. These cocks are often screwed into the column which carries the water gauge, but it is safer to have them directly connected on to the boiler plate.

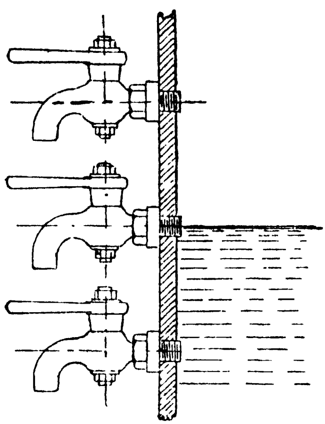


Fig. 10.

THE MAIN STOP VALVE. This is the largest steam valve on the boiler, and it is generally fitted to the highest part of the shell. Its function is to control the flow of steam from the boiler to the main steam pipe, and to shut the steam off completely when required. The body of the casting may be of cast iron or of cast steel; the valve, the valve seat and the nut in which the valve spindle works are made of brass or gunmetal, the spindle should be made of muntz metal. Generally, the working parts of all boiler mountings are made of brass or bronze. The boiler pressure acts under the valve, so that the valve must be closed against the pressure. The valve is generally fastened on to the spindle, and will lift with the spindle. Sometimes a non-return valve is fitted, which allows the steam to flow in one direction only; this valve is not fastened to the spindle, and when the spindle moves the valve will open if there is sufficient pressure to lift it.

When one of a number of boilers is opened out for cleaning and the other boilers are under steam, care must be taken to keep the main stop valve on the empty boiler tightly shut. This is especially important in the case of the valve being fastened to the spindle. If a non-return valve is fitted, and should the spindle be carelessly turned, the valve will be kept on its seat by the steam pressure from the other boilers acting on top of it, ensuring the safety of men who may be working inside the empty boiler. Hence the non-return valve is the safer arrangement. The main stop valves supply steam to the main engines only.

FEED CHECK VALVES. There are two of these valves fitted to each boiler, a main feed check valve generally in use at sea when the main engines are working; and an auxiliary feed check valve,

which is generally used in port when the auxiliary machinery is working, but which may be used at any time if necessary. This makes two separate methods of supplying water to the boiler. The feed check valve is always a non-return valve, fitted with a screwed spindle to regulate the lift. Its function is to regulate the supply of water pumped into the boiler by the feed pump. This valve must have its spindle lifted before the pump is started ; and the valve is lifted by the water from the pump acting underneath it.

The body of the valve is a brass casting, and every part of this fitting is made of brass with the exception of the spindle, which is muntz metal. At the end of every stroke of the feed pump, the boiler pressure on top of the check valve instantaneously closes the valve, and a characteristic rythmic noise is heard when water is being forced into the boiler. The check valves are generally fitted on to the back end plate below the water level.

AUXILIARY STEAM STOP VALVE. This is a stop valve of smaller dimensions than the main stop valve. It is fitted to the highest part of the boiler shell. Its function is to supply steam to the auxiliary machinery in the engine room and to the deck. The auxiliary stop valve and its steam pipes are a separate system, and are not connected in any way to the main steam pipe range. This valve is of the non-return type.

SCUM VALVE. This is a valve fitted to the back end plate of the boiler at the same height as the working water level. An internal pipe leads from the valve into the boiler, and the end of this pipe leads into a sheet iron fitting like a shallow pan about one foot diameter supported by a hanger at the level of the water. The valve discharges into a pipe which is connected to a cock on the side of the ship at the bilge. The function of the scum valve is to discharge the dirt which floats on or near the surface of the water in the boiler. The boiler is pumped up until the water level is a few inches above the level of the scum valve. The cock on the ship's side is now opened, then the scum valve is opened, and the water gauge is carefully watched ; when the level of the water in the gauge glass has been lowered a few inches, the scum valve is closed, then the cock on the side of the ship is closed. The scum valve is fastened to its spindle, and is lifted against the pressure.

THE BLOW DOWN VALVE. This is a valve fitted on the boiler shell or on the back end plate, near the bottom of the boiler. An internal pipe is sometimes fitted from the valve to the lowest part of the boiler. This valve discharges into a pipe which goes to a cock on the side of the ship at about the height of the bilge. One function of the valve is to blow water out of the boiler should the water level be too high ; first the cock on the side of the ship is opened, then the blow down valve is opened. The person operating the valve must watch the water in the gauge glass very carefully,

after first satisfying himself that the water gauge is in perfect working condition. When the water has been lowered to the desired level, the blow down valve is closed, and then the ship's side cock is closed. This valve must be used with great caution, for it can completely empty the boiler. Many accidents have occurred because the water gauge has shown a false level, and too much water has been blown out. It is important to be quite sure of the amount of water in the boiler before blowing any out through the blow down valve. After the fires are allowed to die out, say in port, and the boiler is to be emptied, the blow down valve is used, sufficient pressure being left in the boiler to blow out the water. When the blow down pipe begins to turn cool, the boiler is empty, and the blow down valve must be closed. This valve is also concerned in circulating the boiler when steam is being raised, and this operation is described later.

SALINOMETER COCK. A small cock made of brass is fitted to the back end plate of the boiler near the bottom.

It is the salinometer cock, and it is used to draw off a sample of the boiler water which has to be tested occasionally for density, acidity, etc.

WHISTLE VALVE. This is the valve which supplies steam to the whistle. It is a valve which lifts with the spindle, and it is generally connected directly to the boiler shell in the steam space. This fitting is made entirely of brass.

RUNNING OF BOILERS, When under running conditions at sea, the first consideration is to keep the water level in all the boilers at about the same position, say at half glass. Before the feed pump is started up, the main feed check valves must be opened. The feed pump delivers the feed water into the main feed pipe line. From the main feed line, a separate feed pipe is connected to the main check valve on each boiler.

The steam supplied from all boilers, after it passes through the engines, is condensed into water, and returned to the boilers by the main feed pump. This water must be fed to the boilers so that the level in each is kept the same.

Now it is almost impossible to keep the same steam pressure in all the boilers, especially with hand firing, and an occasional difference of say from 5 to 10 lb. per square inch may occur. The feed water, under pressure from the pump, will flow into the boiler where the steam pressure is least, and the water will be seen to rise in the gauge glass. Water will not flow into the boiler in which the pressure is highest, and the water level in the gauge glass will fall. This slight change in water level must be immediately observed, and precautions taken to correct it. The check valve spindle on the boiler in which the water level is falling is first opened further and the check valve on the boiler which is gaining water is partly

closed down by means of its spindle. The idea is to give a larger area of discharge to the check valve on the boiler which is losing water, and to restrict the area of discharge in the case of the boiler which is gaining water. It is important to open up one check valve before closing down the other. The water levels are by this means adjusted and kept approximately constant. If by carelessness all the check valves are closed at once, a relief valve, which is a spring loaded valve set to open at a pressure slightly above the boiler pressure, should open and prevent the pressure in the line rising to a dangerous extent.

The gauge glass must be constantly under observation. The water gauge should be tested frequently, say about every half hour. Should the glass become discoloured by scale or dirt, a new one must be substituted.

TO CHANGE THE GAUGE GLASS. First shut the water cock, shut the steam cock, then open the drain cock. If there is a guard fitted round the water gauge, remove it. Take out the gauge glass, after screwing back the gland nuts. Clean the gland nuts carefully, and see that they work freely on their threads. Fit new packing on to a new gauge glass; the packing is generally a tapered woodite ring. Put the gauge glass into place, press it down into the water end so far as it will go, screw up the gland nuts and replace the guard. The drain cock is open, the steam and water cocks are still shut. Keep the drain cock open, open the steam cock first; the steam will blow through the glass and out of the drain cock, thus heating up the glass before the full pressure is applied to it. Now open the water cock slowly, then close the drain cock. The full pressure is now on the gauge glass, and the water should show at the correct level. The water gauge should now be completely tested. The steam and water cocks should be opened slowly always.

THE MANAGEMENT AND RUNNING OF STEAM BOILERS

TO OPEN OUT THE BOILER. Steam boilers must be opened out at intervals for cleaning and inspection. There are two methods of emptying the boiler :—By using the blow down valve, and blowing out the water by steam pressure; or by pumping out the water after the steam pressure has been reduced to atmospheric pressure, steam being supplied to the pump from another boiler.

TO BLOW DOWN THE BOILER. Make certain that all the fires are dead and that all steam valves are shut. Open the cock on the side of the ship, then open up the blown down valve. As the water is driven out through the blow down pipe, a loud rumbling noise is heard. In the case of large main boilers of the

Scotch type, blowing down may take 2 to 3 hours. When the boiler is about empty, the noise becomes intermittent and dies down, and the blow down pipe should be felt by the hand. When the pipe becomes cool, the blow down valve must be shut. Another guide as to when the boiler is nearly empty is to watch the pressure gauge, and when this reads about 15 lb. per square inch, the blow down pipe should be tested for temperature by hand. Should the blow down valve not be shut soon enough, water from outside the ship will be forced into the boiler; for the steam remaining inside the boiler becomes condensed with greatly decreased volume, a partial vacuum or condition of very low pressure resulting. After closing the blow down valve and the cock on the side of the ship, the safety valves may be lifted by means of the easing gear; this lets air into the boiler, destroying the partial vacuum formed by the condensed steam. Air may be admitted into the boiler by opening the drain cock of the water gauge and the salinometer cock. In all cases the attendant must satisfy himself that there is atmospheric pressure in the boiler before he attempts to remove the manhole doors. The nuts and dogs are now taken off the studs on the top manhole door, after securing the door with a rope to prevent it falling into the boiler, and the door is pushed in, then removed. The bottom manhole doors are then taken out, and the boiler is left to cool down.

SCALING AND CLEANING. When the boiler is cold, it may be safely entered. It is important to see that all steam and water valves are firmly screwed down by their spindles. Scale is removed from the furnace and combustion chamber plates by chipping and scraping. Modern high pressure boilers should use fresh water feed, and the scale formed should be small in quantity, scraping and brushing with wire brushes should remove it; all accessible heating surfaces being well brushed down. Traces of oil on the shell plates, near the working water level must be carefully removed. Oil is dangerous in boilers, and oil which has deposited on any surface during blowing down should be removed and the plate washed with soda and water. After scaling, the boiler is thoroughly washed out with a hose, all scale and dirt being raked out through the bottom manhole doors.

CARE OF MOUNTINGS. The passages in the steam and water cocks of the water gauge should be cleaned out, and it is advisable to fit new gauge glasses. Valves which may be leaking should be opened up, ground in, then closed up again. The packing in the glands of the valve spindles may need renewing. The safety valves are examined every boiler survey, and generally do not need attention between those periods.

SWEEPING OF TUBES. The smoke tubes should be swept out by wire tube brushes, the soot and ashes removed from the

furnace and combustion chamber, all necessary repairs done to the fire-brick parts, and all burnt or broken firebars renewed.

The cleaning of water tube boilers is done in the same manner as described for multitubular Scotch boilers. Extreme care is taken with water tube boilers regarding the quality of the feed water, which must be perfectly fresh and free from any trace of oil. Special tools are needed to clean the tubes, and it is apparent that scaling will be difficult should a heavy deposit of solid matter occur. With fresh feed water, brushing of the tubes with wire brushes should be sufficient to keep them clean.

TO CLOSE UP THE BOILER. New asbestos joints should be fitted to the manhole doors, the contact faces of the door and the boiler plate being first scraped clean. The joint should be smeared with graphite, this makes the cleaning of the surfaces much easier when the joint has to be renewed. The bottom doors are now put in, tightened up, and the boiler may be filled with water. If the boiler is to be filled from a water boat, or from a water main pipe on the quay, it is usual to put a long hose into the top manhole. The quantity of water varies from about 20 to 45 tons per boiler for the cylindrical type, and from 5 to 10 tons for water tube boilers of ordinary dimensions. Should the water be taken from a tank in the ship, steam will be needed from the donkey boiler to drive the feed pump which will deliver the water through the auxiliary feed check valve, the spindle of which must be lifted. All the steam valves on the boiler are kept closed ; the auxiliary feed check valve, the water gauge cocks, and the small cock to the pressure gauge being the only mountings which are open. When the water has risen to about 6 inches above the top of the combustion chamber, it should be visible in the gauge glass : when the glass is one-third full, there is enough water in the boiler. The top manhole door can now be put in and secured in position.

LIGHTING OF FIRES. Should there be 3 furnaces in the boiler. the fire should be lit in the centre one first ; should there be 4 furnaces, either one or two of the lower furnaces should be lit first. The firebars are covered with coal to a depth of from 4 to 6 inches, and a shovelful of fire is put into the coal, or a small fire can be made from wood and oil. The fire soon spreads along the whole grate, the damper, of course, being open. As the heating must be gradually and slowly done, a small fire only is needed when starting. The process of raising steam is a long one, taking from 18 to 24 hours.

SLOW HEATING. A high pressure cylindrical boiler is a very rigid structure, and should one part of it be raised to a high temperature while the remainder is comparatively cold, high stresses are set up in the material due to the unequal expansion of the plates. This is the reason why the firing must be gradual.

CONVECTION CURRENTS. Water is a bad conductor of heat, and if the whole of the water is to be equally heated, the source of heat must be near the bottom. As the temperature rises, the water expands, and being then less dense, the heated portion rises to the top and is replaced by cold water falling to the bottom. This method of heat transfer is called "convection." As the furnaces do not heat the water which lies in the bottom of the boiler, artificial circulation is used to assist the convection currents; for if this is not done, the water in the bottom may remain cold, even when the water near the water level is hot enough to form steam, and great stresses will be caused in the plates.

CIRCULATING THE BOILER. The blow down pipe has the blow down valve on the boiler at one end, and a cock on the ship's side at the other end; a branch pipe, connected to the blow down pipe between these two fittings, is taken to a suction valve on the auxiliary feed pump, which takes its steam from another boiler. The cock on the ship's side is shut, the auxiliary feed check valve is opened, the pump suction valve is opened, and the blow down valve on the boiler is opened. The pump is started, and water is drawn through the blow down valve into the pump, and delivered back into the boiler through the auxiliary feed check valve. Cold water is thus drawn from the lowest part of the boiler, and pumped in again at a much higher level. The warmer water falls to the bottom and heats the lower plates. Circulating the boiler is important, it should be begun within an hour of lighting the fires and should be carried on continuously, or at intervals, until a pressure of about 50 lb. per square inch is registered upon the pressure gauge. Care must be taken to see that the cock on the side of the ship is kept shut. The water gauge should be under constant observation. The gauge glass will show a higher water level, as the heated water expands. The water level must not be allowed to rise above the steam cock of the water gauge. Should there be too much water in the boiler, then before the water level rises out of sight, some of the water should be pumped into another boiler or over the side. The water level must always be in the gauge glass, and always visible.

After circulating has begun, the boiler bottom should be felt by the hand at intervals, and when the plates are quite warm, the other fires may be lit. A period of about 10 hours should elapse from lighting the first fire, until pressure is shown upon the steam pressure gauge. The water gauge should be tested occasionally to make certain that the correct level is shown. Steam may now be raised slowly, and circulating may be discontinued when about 50 lb. per square inch is shown on the pressure gauge. The pump is stopped, the blow down valve is closed, and the auxiliary check valve is shut down. Steam may now rise to the desired pressure.

Sometimes, instead of the circulating system described, an arrangement called a "hydrokineter" is used. It is essentially

a steam jet inside the boiler, which takes its steam from another boiler. The moving jet of condensed steam and water has a considerable velocity, and the water in the boiler is soon given a circulatory motion. The condensed steam of the jet also gives up its heat to the cold water in the boiler. The object of either method of circulating is the same, and care must be taken to see that the boiler bottom is warmed up soon after the first fire is lit.

In the case of small boilers, when means of circulating is not fitted, great care must be taken in raising steam, and the operation must not be hurried. After one fire has been lit, and a pressure of about 20 lb. per square inch raised, some of the cold water in the bottom may be blown out through the blow down valve, the water gauge being carefully watched during the operation. The water in the gauge glass may be lowered a few inches, but not less than about 3 inches must remain in the glass when the blow down valve is shut. All cylindrical boilers should have some means of being artificially circulated. If steam has to be raised to blow out the cold water, the boiler is doubtless injured during the heating period.

A water tube boiler, being much less rigid than a cylindrical one, is not subject to appreciable strains when steam is raised. The movement of the convection currents is rapid and the various parts heat up at a fairly uniform rate. Artificial circulating is not needed, and steam may be raised in about one hour.

OPENING STEAM VALVES. Main steam pipes are often provided with drain cocks. These cocks should be opened, the pipes completely drained, and the cocks shut again. The main stop valves must be opened carefully. The spindle should be turned through a small angle until a slight hissing noise is heard, then a period should elapse before further turning of the spindle; the idea is to admit the steam to the main steam pipe range gradually, so that the pipes are not suddenly stressed. These precautions should be observed in opening any steam stop valve. When the steam pipes have not any drain cocks fitted, more time should be taken in opening the valves.

WATER HAMMER. Any steam remaining in the pipes after the valves have been closed, condenses into water; should the valves leak somewhat, more water accumulates in the pipes. If now the stop valves are opened quickly, that is carelessly, the steam attains great velocity along the pipe and may carry the water along with it. The impact of this water upon any obstruction in the pipe line is very great; a sudden bend in the pipe, or another stop valve may be such an obstruction, and the pipe may be burst or distorted by the force of the suddenly arrested water. Whenever possible, steam pipes should be carefully drained before turning on the steam, and all valves should be opened very slowly.

FEED WATER FOR BOILERS. Under working conditions at sea, every precaution must be taken to keep the boiler feed water pure. The steam passing through the cylinders carries some of the lubricating oil with it into the condenser, and after the steam is condensed into water all oil and dirt must be filtered out. The filtering apparatus is described later. The condenser tubes, through which sea water is pumped, must be perfectly free from leaks, and all the joints in the condenser which separate sea water from the condensed steam or feed water must be kept tight and free from leakage ; for sea water, generally speaking, is harmful in the boiler. It deposits a hard scale on the heating surfaces, which is objectionable. The scale is difficult to scrape from the heating surfaces, and if allowed to remain on the plates causes a loss of boiler efficiency, as it is a bad conductor of heat. Further, if the scale is allowed to accumulate to any thickness beyond about $\frac{1}{16}$ of an inch, overheating of the plates may occur. The scale which deposits from sea water is made up of carbonate of lime, sulphate of lime and magnesium sulphate.

Salt does not deposit in boilers, for the depositing of salt depends upon the density of the water ; and the water in boilers under modern practice is kept almost fresh. Salt will deposit when the water is 7 times the density of the sea. Sea water contains about 5 ozs. of solid matter to the gallon, the weight of one gallon being about 165 ozs., as compared with 160 ozs. for a gallon of fresh water. We often speak of the density of sea water as " one thirty-second " i.e., $\frac{1}{32}$, which is $\frac{5}{160}$. When we say that the density of the boiler water is $\frac{1}{32}$nd, we mean that it has attained the density of sea water, either by reason of the condenser leaking, or by the deliberate use of sea water feed. Leakage of fresh water occurs from piston rod glands, pump glands, etc., and this loss must be made up to keep the quantity of water in the boilers constant. Fresh water may be carried in the double bottom to be used as boiler feed, or an evaporator may be used ; the evaporator is described later. Sea water should be used in an emergency only ; and if it is used, the boiler density should not be allowed to exceed $\frac{4}{32}$nds. The boiler water is tested for density by drawing off a sample from the salinometer cock, and testing it with a special hydrometer called a Salinometer. With the use of pure fresh feed, lime is put in with the feed water to provide a protective covering on the heating surfaces against corrosion. The lime is put into the feed in the form of " milk of lime," that is, it must be in solution in the water.

The boiler water is tested for slight acidity by using blue litmus paper. After immersion in the water the paper may show a faint pink colour, this denotes an acid condition. Soda put in with the feed water is used to correct this condition.

GALVANIC ACTION. When two diffierent metals are connected together and exposed to the action of an acid or of a saline fluid,

an electrical current is generated. The current may be a slight one, but in any case there goes on an action which reduces the weight of or corrodes one of the metals. The metal which suffers corrosion is said to be electro-positive with regard to the other. The two metals need not necessarily be dissimilar, for two pieces of similar metal at different temperatures when connected and exposed to an acid fluid will generate a slight current. Some of the corrosion which takes place in boilers is attributed to the effect of these slight currents. Zinc is used to prevent the corrosion of boiler plates by those slight currents of electricity. Zinc in the form of plates or slabs is put into metallic contact with the parts to be protected. Zinc is electro-positive with regard to iron and steel, and by its corrosion under the influence of the slight electric currents, protects the boiler plates. Zinc plates are generally renewed when the boiler is opened out for scaling.

CORROSION OF BOILERS: CAUSES. PREVENTION.

CAUSES. OXYGEN combines readily with iron to form oxide of iron, often called " iron rust." Water always contains dissolved air. Hence the feed water carries air into the boiler, and the oxygen in the air may attack any unprotected surface.

ACIDS from the lubricating oils used for cylinders and piston rods, passing with the condensed steam into the feed water. When animal oils are raised to a high temperature they decompose, and one of the substances set free is stearic acid ; when vegetables oils decompose by heat, palmitic acid is set free. The animal oils are tallow and sperm oils ; the vegetable oils are cotton, colza or rape, castor, cocoanut, etc. These oils are not suitable for the internal lubrication of cylinders and slide valves, as the temperature to which they are exposed will decompose them, setting free their harmful acids. Pure mineral oils, distilled from the crude oils found in the earth's crust, should be used. These mineral oils do not decompose into acids, and oils of this kind only should be used for internal lubrication.

GALVANIC ACTION has already been discussed on page 31.

DECOMPOSITION OF SOLIDS in sea water. Magnesium Chloride, one of the salts in solution in sea water, may decompose under the action of the heat and ultimately form hydrocholic acid. This acid will dissolve iron, forming chloride of iron which by a further reaction changes to black oxide of iron.

STRAINS which cause mechanical grooving. There is a bending action on all plates which are fastened together by lap joints, and

this action occurs close to the joint. The strains due to this bending action will vary with slight changes in temperature and a small but insistent working of the plate may cause surface cracks, which soon extend or become deepened by the attack of any acid in the vicinity, ultimately developing into small grooves.

PREVENTION, FEED HEATING. Much of the air in the feed water may be eliminated by heating the feed before it is pumped into the boilers. The method of heating the feed is described later. In a special arrangement called the "closed feed system," the feed water is kept from contact with the atmospheric air, and the evils due to the presence of oxygen in the boiler are greatly reduced. Also, by using independent feed pumps, more air is kept out than if pumps driven off the main engines are used; for pumps driven by the main engines work at higher speeds than independent pumps, and need air to make them work without shock. Feed heating also prevents straining and therefore prevents mechanical grooving. The hotter the feed is made, the less the temperature difference between different parts of the boiler; and a more uniform temperature means less strain.

PURE MINERAL OILS. Pure mineral oils only should be used for cylinder lubrication and for piston rods, as they cannot, by decomposing, give up acid to the feed water.

All oil should be filtered out of the feed water. Oil in the boiler in any form is harmful. Oil is a bad conductor of heat, and should any oil present become attached to small pieces of scale, the mass may sink upon a heating surface, cause overheating and collapse of the plate. To such overheating, many accidents to the combustion chambers, tubes and furnaces of boilers have been attributed. This also shows the advantage of frequently scumming the boilers by means of the scum values, to get rid of dirt and oil which may float on the surface of the water. As a general protection against acids and air which may get into the boiler, lime in the form of "milk of lime" is put into the feed water. This lime being in solution is given up in the boiler and deposited as a thin protective scale on the heating surfaces. Soda may be used to correct acidity.

ZINC is used to protect the plates against galvanic action. As already stated, zinc is electro-positive with regard to iron, and when these two metals are exposed to an acid or saline fluid, it is the zinc that suffers corrosion, the iron or the steel remaining unharmed.

SEA WATER must be kept out of the boilers, and the evils of the decomposition of the magnesiam chloride avoided. Hence the condenser must be kept in perfect order, and all extra or "make up" feed water must be perfectly fresh.

STRAINING may be prevented by feed heating. As previously pointed out, great care must be taken in raising steam, so that

heating takes place gradually. Circulating the boilers soon or immediately after setting away the first fire, is of the greatest importance.

CORROSION may be general or local. General corrosion is seen in the roughening of the whole surface of the plate, and the loss of plate thickness may be small or considerable. Intense local corrosion is seen in the form of pits or depressions in the plate, and the loss of plate thickness may be considerable at the bottom of the pits ; the material surrounding the pits may be quite unaffected.

The parts most generally affected are :—The shell plates at the water level ; the necks of stays and tubes ; the combustion chamber back and bottom plates ; and the furnaces, along the line of firebars and on the bottom. Slight general corrosion and pitting may, however, occur anywhere in the boiler. The importance of periodic examination will be evident, and it is desirable that all parts of the boiler should be made as accessible as possible.

COAL AND OIL BURNING.

COMBUSTION is a chemical action during which oxygen combines with some other substance, heat being evolved during the process. This action may take place slowly, rapidly, or almost instantaneously. The rusting of iron is an example of slow combustion. The burning of coal or oil is rapid combustion. The firing of an explosive mixture is an example of combustion which is almost instantaneous.

CARBON AND HYDROGEN are the main constituents of all fuels, and it is the combination of these elements with the oxygen of the air which produces the heat in the furnaces or in the cylinders of oil engines ; this heat being converted into mechanical work by the main engine. Air may be supplied to the furnaces by " natural draught," the intensity of this draught depending on the height of the funnel above the fire grate ; or the air may be forced into the furnace by a fan which is driven by a small engine, the system being generally called " forced draught."

If insufficient air is supplied the combustion will not be complete ; if too much air is supplied, more heat is carried away in the funnel gases by this excess air or by the exhaust gases of an internal combustion engine, and in each case the efficiency will be lowered In the burning of coal, or oil, the fuel must be intimately mixed with air.

COAL. Coals differ greatly in composition and calorific value. Welsh anthracite contains about 90 per cent. of carbon. It is heavy, hard and lustrous, it is not easy to ignite, it burns with little flame,

gives out intense heat, and is almost smokeless. Most coals used for steam purposes are classed as bituminous and semi-bituminous, the carbon being from 78 to 88 per cent. Bituminous coals cake together when burning, flame plentifully, and give off smoke. **THE CALORIFIC VALUE** of steam coal varies from about 10,000 to 14,000 B.T.U. per pound for British and American coals, and considerably less than this for Indian coals. A table of approximate composition for good coals, and for oil is given in percentages by weight.

Fuel.		Carbon	Hydrogen	Oxygen	Sulphur	Ash
Coal.	Welsh	88	4	3	1	4
,,	Newcastle .	83	5	4	1	7
,,	Indian ..	56	volitile m	atter 24·5	1·5	18
Oil.	Mexican	83·5	12	1	3·5	
,,	Persian	86	12	0·5	1·5	

An average value of the specific gravity of coal is 1·4. Welsh coal stores at about 40 to 42 cubic feet per ton. Newcastle and Scotch coal store at from 43 to 45 cubic feet per ton. Indian coal contains much more ash than British coal, and is more difficult to work on the fire.

COAL FIRING. The fires should be kept as bright as possible, the fuel being kept incandescent ; this result is best obtained by firing at frequent intervals, the coal being supplied in small quantities. The bars must be kept clear of " clinker " or fused ash, and the ashpits kept clear of ashes. The fires must be cleaned about every 12 hours ; the accumulated ash and cinder being completely removed from the fire bars. Any fire bars which have become burnt,or which have sagged by overheating, must be renewed.

With natural draught from 16 to 20 lb. of coal may be burnt per hour per square foot of grate ; with forced draught from about 26 to 30 lb. per square foot may be burned.

THE FUEL OILS used for firing are viscous black coloured fluids, of specific gravity from about 0·9 to 0·96. The flash point of these oils is required to be above 150° F., and generally is not below 180° F.

THE FLASH POINT is the temperature to which an oil must be heated to give off vapours, which when mixed with a definite amount of air produce explosive mixtures.

THE FIRING OR BURNING POINT is that temperature at which oil vapours are given off in sufficient quantity to take fire when ignited, and are generated quickly enough to maintain a flame over the surface of the oil.

No difficulty has been experienced in the safe storage and burning of oils with a flash point of 150° F. and upwards.

THE SPECIFIC GRAVITY of oil is often required. The weight of a given volume of the oil is compared with the weight of the same volume of water. Thus :—

$$\text{Specific Gravity} = \frac{\text{Weight of given volume of oil}}{\text{Weight of equal volume of fresh water}}$$

The Specific Gravity is generally taken at 60° F.

BEAUME density is a common way of stating density for fuel oils, and stated in degrees.

$$\text{Degrees Beaumé} = \frac{140}{\text{Sp. Gravity at } 60^\circ \text{ F.}} - 130.$$

$$\text{Or Sp. Gravity at } 60^\circ \text{ F.} = \frac{140}{130 + \text{Degrees Beaumé}}$$

The greater the specific gravity of an oil, the smaller is the Beaumé reading. Thus, oil of Sp. Gr. 0·88 would read 29° Beaumé, whilst oil of Sp. Gr. 0·92 would be registered as 22° Beaumé.

THE CALORIFIC VALUE of fuel oil varies from about 17,000 to 19,000 B.T.U. per pound.

OIL FIRING or burning. In this system the oil, after heating and filtering, is forced through a small hole in the burner ; this breaks up the oil into a very fine spray or mist, which easily mixes with air, and burns readily when ignited by a flame. The complete system consists of :—

SETTLING TANKS placed in the stokehold, into which the oil is pumped from the double bottoms. A suction valve must be fitted on this tank, and the spindle of this valve must be extended up to the deck. This enables the oil to be " shut off " at the source in case of fire. The oil is drawn by a pump from the settling tank, through an apparatus called the **COLD FILTER,** where the larger impurities, sand, dirt, etc., are intercepted and periodically cleared away. From the cold filter the oil passes into the pump.

THE PUMP discharges the oil at a pressure of from 30 to 120 lb. per square inch. The pressure used depends upon the kind of oil and the design of the burner.

THE HEATER. The pump delivers the oil to the heater, in which the oil is raised in temperature to about 200° F., the temperature depends upon the kind of oil. Heating the oil reduces

its viscosity, makes it flow more readily, enables it to be forced through a hot filter of smaller mesh, and assists in the atomisation process at the burner. The heater consists of a coil of steel tube through which the oil passes, the coil being contained in a cylindrical vessel. Steam is admitted to this cylinder, and heat from the steam is transmitted through the tube to the oil inside. The oil passes from the heater to

THE HOT FILTER, where any dirt which may close the small hole in the burner is intercepted and strained out. From the hot filter the oil is led to a distribution box on the boiler end, and then by small pipes to the burner which protrudes through the furnace front into the furnace.

Filters, heater and steam pump are in duplicate, and are fitted with an arrangement of valves so that either may be used while the other is being overhauled. A master steam valve controls the steam to the entire system, and it has an extension spindle leading up to the deck, so that the steam can be completely shut off in case of fire.

CIRCULATING VALVE. This is a valve fitted on the distribution box on the boiler end, and from it a pipe leads to the suction side of the oil pump. When the burners are shut off, oil may be pumped continuously to and from the distribution box by opening this valve. It is used to assist in the heating of the oil during the process of lighting up.

A diagrammatic sketch of an oil burning installation is shown in Fig. 13.

LIGHTING UP. Open up the following valves:—Suction valve on the settling tank, inlet and outlet valves on cold filter, suction and delivery valves on pump, inlet and outlet valves on heater, and the circulating valve. Open up the master steam valve, and then the steam inlet to the heater; the drain valve on the heater is now slightly opened. Steam is opened to the oil pump and the oil is circulated round the system, and will be heated up to the required temperature. Thermometers are placed so as to record the temperature of the oil. When the oil has reached the desired temperature, the circulating valve is closed, and the steam to the pump adjusted so as to raise the pressure of the oil.

AIR IS ADMITTED to the furnace and allowed to pass through for a few minutes before attempting to **LIGHT THE FIRE.** It is very important to observe this latter precaution. Fatal accidents have occurred by its neglect. If the valve leading from the distribution box to the burner is leaking, oil may get into the furnace, and if the boiler is hot, gases are given off by the oil. These gases mixing with the air form an **EXPLOSIVE MIXTURE,** and if a light be applied, a **VIOLENT EXPLOSION** will result. By admitting

the air to the furnace for a few minutes before a torch is applied to the burner, any explosive mixture is swept out.

Note.—As there is no main damper fitted in the funnel with oil fuel, there is always a clear passage for the air.

A torch is now inserted into the furnace, and the valve on the distribution box is opened admitting oil to the burner. The spray of oil issuing from the burner is ignited and burns with an intensely hot bright flame.

WHEN STEAM IN NOT AVAILABLE for the heater, and the pump, other means are provided for heating the oil. In one system a very small boiler is provided which is heated by a paraffin blow lamp. The oil is pumped through a coil in this boiler by a hand pump and is heated and raised in pressure sufficiently to light up one or two fires until steam is raised in one or the main boilers or in a donkey boiler.

CONDITIONS OF COMBUSTION are indicated by the smoke issuing from the funnel. When the correct amount of air is mixed with the oil, there should be little smoke.

BLACK SMOKE indicates that not enough air is being admitted, or that the pressure or the temperature is not sufficiently high, or that the burner orifice is choked.

WHITE SMOKE is formed when too much air is admitted.

INTERMITTENT BURNING or spluttering at the burner is caused either by water in the oil, or by the oil being too hot.

FIRE EXTINGUISHING APPARATUS must be carried.

SAND is useful for putting out small fires.

CHEMICAL EXTINGUISHERS which form a foam of bubbles of carbon dioxide gas are often fitted. In these, hydrochloric acid is caused to act on carbonate of lime. This produces the gas and the bubbles are made by soap bark mixing with the liquid. The foam excludes the air from the fire and thus stops the combustion by starving the flames of oxygen.

These extinguishers are made in various sizes from two gallon portables up to three hundred gallon types fixed high up in the ship.

STEAM EXTINGUISHERS, A series of perforated pipes are placed under the stokehold plates. In case of fire, steam is allowed to escape from the pipes. The steam excludes the air and the fire is put out for want of oxygen.

WATER JETS in the form of fine spray are sometimes used.

Fire fighting equipment in engine and boiler rooms are provided as follows.

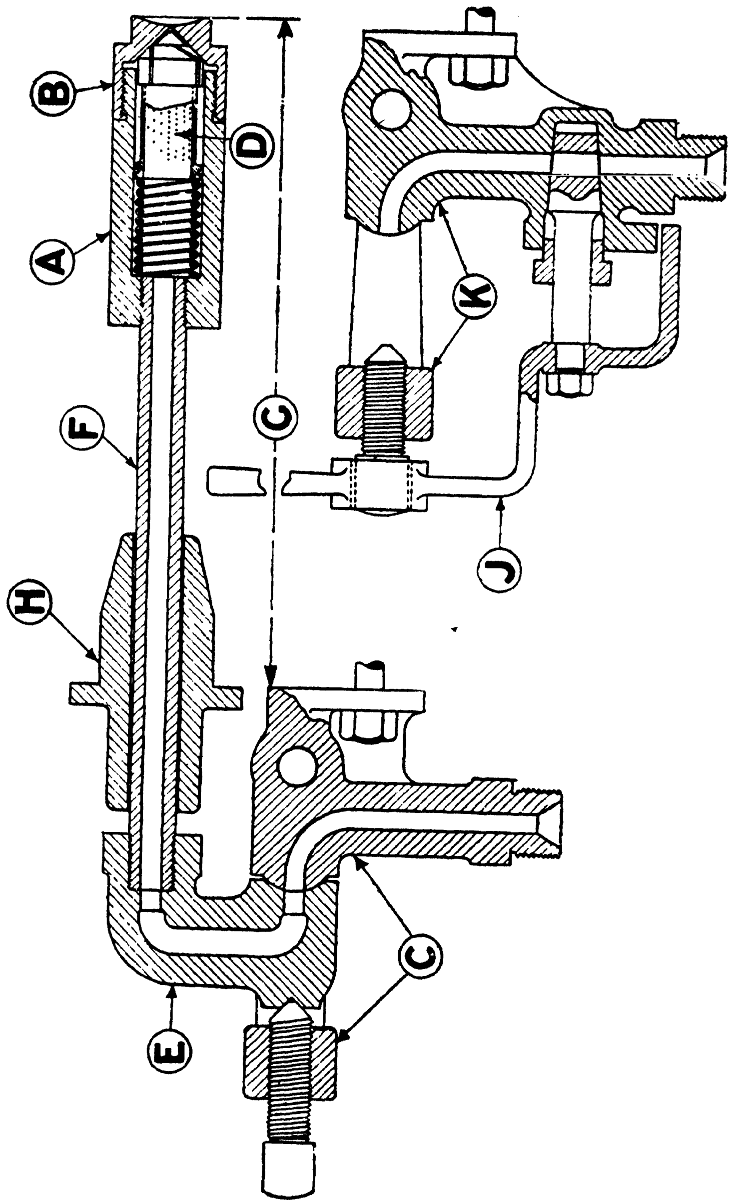


Fig. 11.

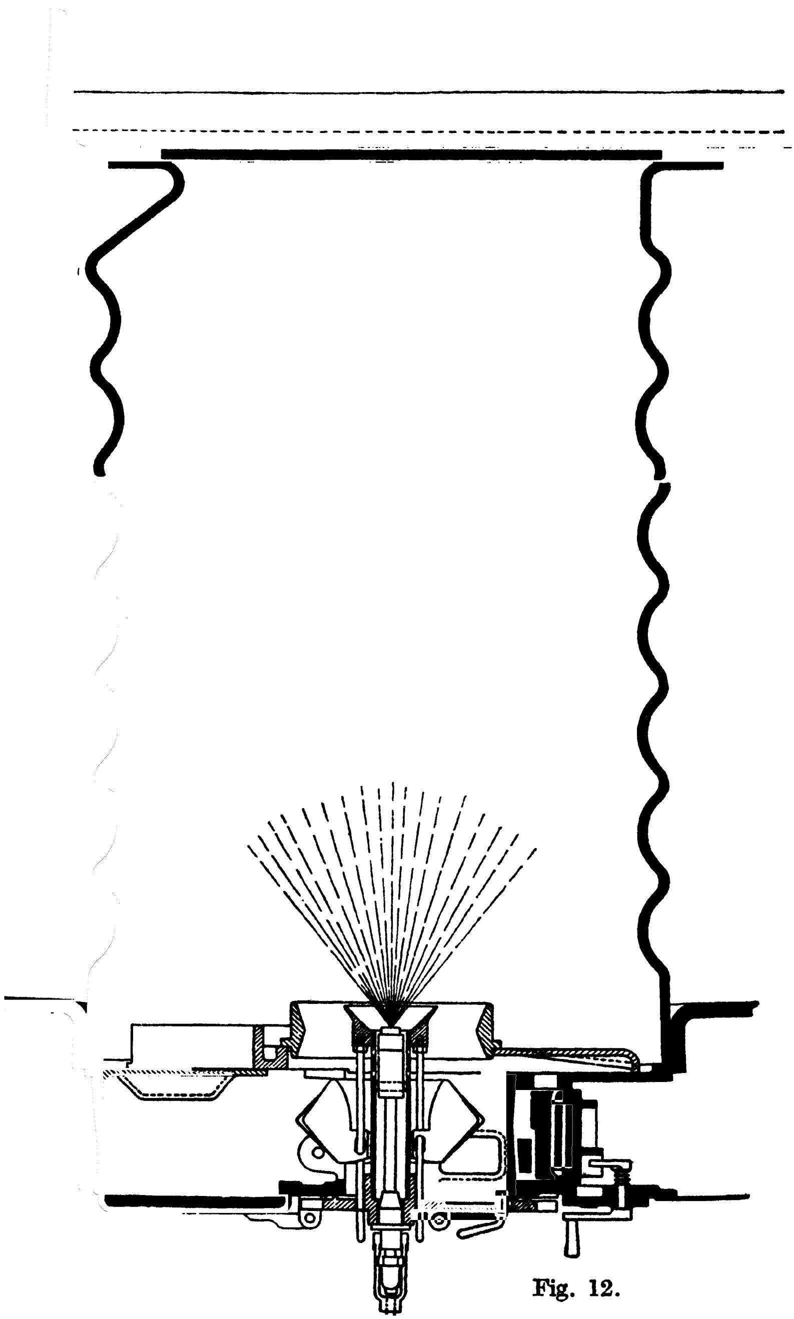
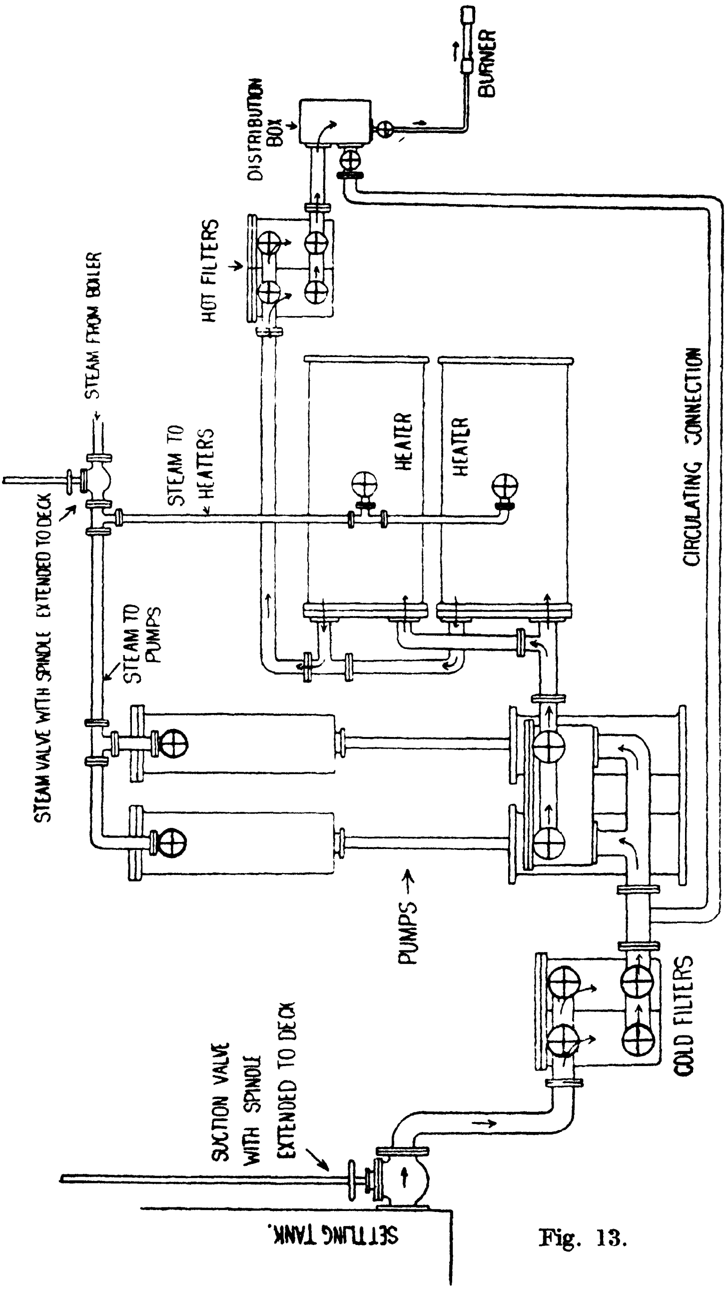


Fig. 12.



Diagrammatic Sketch of Oil Burning Arrangement.

Fig. 13.

COAL FIRED SHIPS must be provided with apparatus whereby at least two powerful jets of water can be rapidly and simultaneously directed into any part of the coal bunker spaces, boiler rooms and machinery spaces. In addition at least two portable fluid fire extinguishers must be provided in each of the boiler rooms and machinery spaces.

OIL FIRED SHIPS. In addition to the water jets as provided in the case of the coal fired ships there must be provided :—

(a) Conductors for spraying water on oil without undue disturbance of the surface.

(b) A receptacle containing at least 10 cubic feet of sand in each firing space and suitable scoops for distributing the sand.

(c) Two portable extinguishers constructed to discharge froth in each boiler room and in each of the machinery spaces in which a part of the oil fuel installation is situated.

(d) Apparatus whereby froth can be rapidly discharged and distributed over the whole of the bottom of any boiler room or machinery space, which contains part of the oil fuel installation, to a depth of six inches. This apparatus must be controlled from outside the compartment concerned.

MOTOR SHIPS. In addition to the two jets mentioned in the foregoing cases with conductors for spraying the water, one ten gallon extinguisher discharging froth and one two gallon portable extinguisher must be provided for each 1,000 B.H.P. of the engines. The number of the latter must not be less than two and need not exceed six. If a donkey boiler is fitted in a machinery space, a thirty gallon extinguisher must be fitted in place of the ten gallon extinguisher mentioned above.

THE CAUSES OF FIRES are varied but the most common are the following :— Lack of cleanliness. Oil fuel from burners or glands of valves or pumps allowed to accumulate. Leaks on the hot sides of oil fuel installations are particularly dangerous. Naked lights used in spaces where oil vapour may be found. Leaky piston rings and over lubrication of the pistons may cause fires in the scavenge air trunk of oil engines. With engines having forced lubrication and enclosed crank cases, the crank case space may be filled with oil in the form of a mist. An overheated bearing may ignite this oil and cause a serious explosion. In oil burning boiler furnaces, air should always be allowed to pass through the furnace for two or three minutes before lighting up. If the burner is leaking the oil passing into the furnace may be vapourised by the heat of the boiler. This vapour together with the limited air supply may form a very explosive mixture and applying a light may cause a violent explosion. Serious accidents have resulted from neglect of this precaution.

VENT PIPES from tanks should have gauze wire fitted over their open ends. The wire gauze has a large surface which absorbs heat rapidly and cools any burning gases near the pipe end to below the temperature at which they will burn. Fire is thus prevented from passing down the pipe to the oil in the tank.

In the illustration, Fig. 11, is shown the White oil burner. The letters refer to the different parts of the burner, as follows:—A—Burner body. B—Burner tip. C—Detachable union and yoke. The screw presses the burner head E on the nipple of the union, and makes an oil tight joint. D is an additional strainer in the burner body, and F is the burner tube.

In the other part of the sketch a safety device is shown which renders it impossible to remove the burner before the oil is shut off.—The handle of the cock J has a guard formed on it which covers the end of the screw when the cock is in the open position. Moving the guard clear of the screw shuts the cock, and thus shuts off the oil to the burner.

In the second illustration, Fig. 12, a section of a furnace and a White oil furnace front arrangement is shown.

ADVANTAGES OF OIL FUEL. Less stowage space needed, easy to stow, no trimming as with coal; great calorific value, and therefore less bunker space needed for the same length of passage, for equal heating value the bunker space is about $\frac{4}{7}$ of that needed for coal. There is more control of the steam pressure, a steady pressure of steam being easily maintained, and a smaller staff of firemen can carry on the work.

DISADVANTAGES. There is a greater risk of fire; the cost of repairs for tanks is greater; in some trades it may not be possible to obtain oil. The relative costs of the two systems of coal and oil burning depends upon where supplies are bought, and is a matter of circumstances and position. All tanks must be steamed out before entering.

CHAPTER III.

HEAT, PROPERTIES OF GASES, STEAM, Etc.

HEAT is a manifestation of energy. The ultimate particles or molecules of a substance are in a state of incessant motion within the substance, and this motion becomes more rapid when heat is given. Heat may therefore be called a form of vibratory energy. When heat is given to a substance some of its properties are changed; it can now excite a different sensation when touched, its volume will, generally, increase, its magnetic properties may be altered. The weight of the substance will be the same but something has been gained ; the substance has received energy in the form of heat, and is now in a higher state of energy.

TEMPERATURE. The temperature of a body is a measure of the intensity of heat contained in the body. For measuring temperatures up to about 600° F., mercury thermometers are used. The freezing point of pure water and its boiling point at the normal pressure of the atmosphere, 14·7 lb. per square inch, are known to be constant temperatures, and these fixed points are used in the graduation of thermometers. The freezing point on the Fahrenheit scale is 32°, the boiling point is 212° ; on the Centigrade scale, freezing point is 0°, boiling is 100°

UNIT OF HEAT. The unit of heat in the British system is the British Thermal Unit, generally written B.T.U., and it is defined as the quantity of heat necessary to raise one pound of water one degree Fah.

SPECIFIC HEAT. Different substances have different capacities for storing heat. It takes one B.T.U. to raise one lb. of pure water one degree Fah., but it takes only 0·095 B.T.U. to raise the temperature of one lb. of copper one degree Fah. ; so that the quantity of heat contained in one lb. of each of these substances, although they might be at the same temperature, is not the same, and the distinction between temperature and quantity of heat should be noted. The specific heat of a substance is the quantity of heat in B.T.U. necessary to raise one lb. of the substance one degree Fah., compared with the quantity of heat needed to raise one lb. of water one degree Fah. The specific heat of water varies slightly with the temperature, but for all practical purposes it may be taken as unity or 1.

ENERGY is the capacity for doing work.

WORK is expressed as force multiplied by distance, and its unit is the **foot pound** ; the unit of work is the quantity of work necessary to raise one pound through a vertical distance of one foot.

CONSERVATION OF ENERGY. Energy, like matter, can neither be created nor destroyed. Coal burnt on a grate, generating steam in a boiler, and this steam doing work in an engine is an example of the **transformation of energy** from one state to another; but we did not create the energy held originally in the coal, nor do we destroy the energy The energy after we are done using it still exists, but perhaps in a form such that we can no longer avail ourselves of it. Energy may be dissipated or reduced to a form or state in which it is no longer of service to us in engineering. The statement that energy can neither be created nor destroyed is called the law of the conservation of energy.

HEAT AND WORK are mutually convertible one into the other, this is a transformation of energy. It is a matter of common experience that hammering or filing a piece of metal will make it hotter; the energy given out by the hammer or the file has made its re-appearance in another form. It has raised the temperature of the piece of metal. This is the conversion of work into heat. It is more difficult to convert heat into work.

THERMO-DYNAMICS is the subject which deals with the conversion of heat into work.

JOULE'S EQUIVALENT. The first law of thermo-dynamics states :—" Heat and mechanical work are mutually interchangeable or convertible." The rate of this exchange was first determined by Dr. Joule, who discovered that one B.T.U. is equivalent to 778 foot lb. of work.

CONVERTING HEAT INTO WORK. Heat will flow from a hot body to a colder one. In any heat engine, work is done by reducing the temperature of the working substance, by allowing the heat to flow from a region of high temperature to one of much lower temperature, the heat given out being partly converted into useful work. The working substance, steam or air, must be elastic, and capable of expanding in volume as its temperature and pressure decrease.

THE THREE STATES OF MATTER. Most substances may exist in the form of a solid, or of a liquid, or of a gas, one form being convertible into the other. Water, the liquid, can be converted into the solid form of ice, or into the vapourous form of steam. Many gases can be turned into the liquid form, and then into the solid form. Each form is associated with a different degree of energy. In the gaseous form, more heat energy is contained in a substance, than when it is in the liquid form; and in the liquid form it contains more energy than when it is in the solid form.

A PERFECT GAS is a gas which obeys Boyle's law. For engineering purposes, a perfect gas is a substance which remains in the gaseous state during the whole cycle of operations in a heat engine.

At one time, it was thought that the gases of the atmosphere could not exist except in the gaseous form. Now it is known that all gases can be liquified, under certain conditions of temperature and pressure. We may say that for practical purposes, a perfect gas is a substance which remains in the gaseous form through a wide range of temperature and pressure. Air can be regarded as a perfect gas. Steam is not a perfect gas ; it is a vapour, and does not follow Boyle's law.

PROPERTIES OF GASES. A liquid of less volume than the vessel which contains it, will only partly fill the vessel. Any volume of a perfect gas if put into a vessel of larger volume than itself, will at once fill every part of the vessel. The difference between a liquid and a gas lies essentially in their different elastic or expansive properties, and it is this elastic property of gases and vapours which is so useful in the cylinders of heat engines. The term " working fluid," is the name given to the gaseous substance employed to do work in engines, whether that substance be a mixture of gases or steam.

ABSOLUTE TEMPERATURE. Now whereas all solids and liquids when heated, expand at different rates, all gases expand at the same rate when heated, and contact at the same rate when cooled. One cubic foot of a perfect gas contracts $\frac{1}{492}$ part of its volume when cooled one degree Fah., at 32° Fah. This suggests that if the gas is cooled 492° below 32° Fah. that a state called the absolute zero of temperature will be reached. This absolute zero is 460° below 0° on the Fah. scale, and 273° below 0° on the Centigrade scale. The absolute temperature is found by adding 460 to the reading on the Fah. scale, and by adding 273 to the reading on the Cent. scale.

BOYLE'S LAW. The pressure of a perfect gas varies inversely as its volume, if the temperature remains constant. This is expressed mathematically as $p\ v$ = constant, or the product of pressure and volume is constant.

CHARLES' LAW. The volume of a perfect gas varies directly as its absolute temperature, if the pressure remains constant ; also the pressure of a perfect gas varies directly as its absolute temperature if the volume remains constant.

ISOTHERMAL EXPANSION. A gas is said to expand isothermally when its temperature remains the same during the operation. An amount of heat, equal to the external work done, must be supplied to the gas during the operation. In short, as the gas expands and does work, heat must be given to it to keep its temperature constant.

ADIABATIC EXPANSION. A gas is said to expand adiabatically when it does work at the expense of its own heat energy, the temperature falling during the operation. During the expansion, no heat is given to the gas, nor is any heat allowed to escape from it. Isothermal and adiabatic operations cannot be completely carried out in practice. They form theoretical standards with which to compare the performance of gases in actual engines.

AIR. Atmospheric air consists of approximately 23 parts of oxygen and 77 parts of nitrogen, by weight. Atmospheric air is the working fluid of internal combustion engines, and the fuel which heats it is an inflammable vapour or oil, the two being intimately mixed together.

STEAM.

SENSIBLE HEAT. When heat is given to a substance, if the temperature of the substance rises, the heat given is said to be " Sensible heat " ; if sensible heat is taken away from a substance, the temperature of the substance falls.

CHANGE OF STATE. It has been shown that a substance may exist in the solid form, in the liquid form, or in the gaseous form, and that it may be changed from one form into another. One lb. of ice contains less heat than one lb. of water, and one lb. of water contains less heat than one lb. of steam. In converting one lb. of water at 32° Fah. into ice at 32° Fah., the temperature of the substance does not change ; but to change its physical state from the liquid into the solid form heat must be taken from it. The heat taken from water at 32° Fah. to convert it into ice at 32° Fah. is called the " latent heat of water," and its amount is 143 B.T.U. per lb. The heat given to one lb. of water at boiling point in the atmosphere, that is 212° F, to convert it into steam at 212° Fah. is called the " latent heat of steam," and its amount is 970 B.T.U. per lb., a large quantity of heat.

LATENT HEAT is the heat given to a substance to change its physical state, the temperature of the substance remaining the same during the change. In an open vessel, water may be raised in temperature to 212° F., the heat given to the water during its rise in temperature being sensible heat. If more heat be given to the water now, its temperature will not rise above 212° F. ; what becomes of this heat ?—the greater part of it goes to change the physical state of the stuff from the liquid into the gaseous form. As a further example, consider the cooling of water in a canvas bag, or in an unglazed clay vessel. Water drips or " sweats " through the pores of the vessel. Now dry air has an affinity for water vapour, but the air cannot take up the drops of solid water lying on the outside of the vessel ; this water needs latent heat to change it into the vapourous form, when it is readily absorbed by the air. The water on the outside of the vessel takes latent heat from the water inside which is thereby cooled, sometimes to several degrees below the temperature of the surrounding air. The necessary conditions are :—The vessel must be porous, and drip water ; the air must be dry, for if the air is already saturated with water vapour it cannot take up vapour from the water on the surface of the vessel. If the air is already saturated, the temperature of the water in the vessel will be the same as that of the surrounding air.

SATURATED STEAM is steam in the presence of the water from which it is generated ; it contains no particles of water in suspension, it is invisible and is often called " dry steam." It is not a perfect gas, but it possesses the same elastic property as a perfect gas. When water is heated in a closed vessel like a boiler, its boiling point rises with the pressure inside, the steam generated having the same temperature as the water. Steam in the presence of the water from which it is generated can have only one temperature for a given pressure. The pressure gauges fitted to steam boilers and engines give pressures above the atmospheric pressure.

THE ABSOLUTE PRESSURE is the pressure per square inch reckoned from zero, so that to obtain the absolute pressure, the atmospheric pressure must be added to the gauge pressure ; adding 15 lb. per square inch to the gauge pressure is sufficiently correct for ordinary purposes. Steam at a pressure of 100 lb. per square inch absolute has a temperature of 327·8° Fah., and steam at 200 lb. per square inch absolute has a temperature of 381·9° Fah. Steam tables are published which give the temperature, the latent heat and the total heat of one lb. of steam for any pressure.

THE TOTAL HEAT OF STEAM is made up of the sensible heat plus the latent heat. The steam tables give the total heat of steam reckoned above 32° Fah. The latent heat of steam decreases as the pressure and temperature increase. How much heat is put into one lb. of water at 150° Fah. to convert it into steam at 200 lb. per square inch absolute.? The steam tables give the temperature as 381·9° Fah. and the latent heat as 846·6 B.T.U. per lb.

Sensible heat given to raise water to 381·9° Fah. = (381·9 — 150) = 231·9 B.T.U. per lb.

Latent heat to convert water at 381·9° into steam at 381·9° = 846·6 B.T.U. per lb.

Total heat given = 231·9 + 846·6 = 1078·5 B.T.U. per lb.

WET STEAM. When steam contains moisture, or particles of water in suspension, it is said to be " wet steam." This means that the evaporation is not complete, and that the whole of the latent heat has not been given.

THE DRYNESS FRACTION. In one lb. of wet steam, if there is x lb. of water, then there is $(1 - x)$ lb. of steam, and the dryness fraction is $\dfrac{1 - x}{1}$

Thus steam of dryness fraction 0·9, has 0·1 of its weight in the form of water. To generate steam 0·9 dry, takes only 0·9 of the latent heat necessary to produce dry steam at the same temperature ; but the sensible heat given to the water is the same in both cases.

Thus in the example given previously, suppose that we require to find the total heat needed to convert one lb. of water at 150° Fah. into steam of dryness 0·9 at 200 lb. per square inch absolute and a temperature of 381·9 Fah.,

Sensible heat given to water = (381·9 — 150) = 231·9 B.T.U. per lb.

Latent heat given = 846·6 × 0·9 = 761·94 B.T.U.

Total heat given = 761·94 + 231·9 = 993·84 B.T.U. per lb.

THE SPECIFIC VOLUME OF STEAM is the volume, in cubic feet, of one lb. of steam at a given pressure. When water is converted into steam it becomes endowed with a new property; the liquid has practically no elasticity, the steam into which it is converted has great elasticity, and may be expanded or compressed through a great range of volume. In changing from a liquid into a vapour the volume is very greatly increased. The volume of one lb. of water is about 0·016 cubic foot, the volume of one lb. of steam at atmospheric pressure is 26·8 cubic feet. The volume of one lb. of steam at 100 lb. per square inch absolute is 4·44 cubic feet, and at 200 lb. per square inch absolute it is 2·3 cubic feet. It is important then to note that a large volume of steam will condense into a very small volume of water.

SUPERHEATED STEAM. When steam is taken away from the presence of the water from which it is generated, it may have heat given to it to raise its temperature without raising its pressure; in other words, heat is given at constant pressure, and the steam is said to be superheated. Superheated steam is steam which has had its temperature raised above the temperature of saturated steam of the same pressure. Thus more heat and therefore more work is stored in the steam per lb. Since the pressure remains constant, the volume increases when heat is given, and the volume of one lb. of superheated steam is considerably greater than the volume of one lb. of saturated steam at the same pressure.

EXPANSION OF STEAM.

DIAGRAM OF WORK. In a steam engine of the commonest form, work is done by a piston moving to and fro in a cylinder. The total force on the piston is :—Area of piston in square inches multiplied by the steam pressure in lb. per square inch; and the work done in one stroke of the piston is :—Total force on the piston multiplied by the length of the stroke in feet; this gives foot lb. of work.

CONSTANT PRESSURE. It is easy then to find the work done by the steam, if the pressure is kept the same throughout the stroke. Since the work done is made up of two quantities multiplied together, and as an area is two quantities multiplied together, work done may be represented by an area.

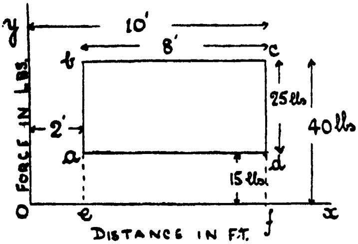


Fig. 14.

Let two lines $o\ y$ and $o\ x$ be at right angles, meeting in the point o.

Let $o\ y$ represent force, say in pounds.

Let $o\ x$ represent distance, say in feet.

Then since force multiplied by distance is work, any closed area between the lines $o\ y$ and $o\ x$ must represent work. o is the **origin.** It is the point from which we begin to measure both force and distance.

Let $a\ b$ be a constant force, exerted through distance $b\ c$, then work done is $a\ b$ multiplied by $b\ c$.

Work done = Area $e\ b\ c\ f$ minus area $e\ a\ d\ f$.

" " $= (40 \times 8) - (15 \times 8) = 25 \times 8 = 200$ foot lb.

VARYING PRESSURE. When a force which varies in value moves through a distance, the work done is found by first finding the mean or average force and then multiplying it by the distance it moves. The diagram $g\ h\ k\ n\ l$ represents the work done by a force which is constant from g to h, then falls in value from h to k. Divide the area up into a number of equal parts, say 10 spaces, then draw dotted lines as shown in the middle of each space. Measure the lengths of these dotted lines by a suitable scale; add these lengths together, then divide by 10. The result is the mean height of the diagram, representing the mean force, and the mean force multiplied by the length of the diagram (here $l\ n$) is the area which represents the work done in foot lb.

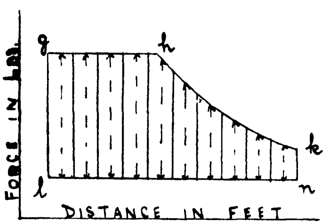


Fig. 15.

NON-EXPANSIVE WORKING OF STEAM. Let us suppose that we have an engine with a cylinder 1·5 square feet in area, and that the piston working in it has a stroke of 2 feet. Also let us assume that we can take steam from some boiler at a pressure of 100 lb. per square inch absolute, and that we have an arrangement which enables us to give steam to our engine through the whole length of the stroke, or by means of which we can stop the supply of steam at any desired position before the piston reaches the end of its stroke; the position at which we stop the supply of steam is called the " point of cut off," and it is expressed as a fraction of the stroke.

Let steam be supplied for the whole length of the stroke.

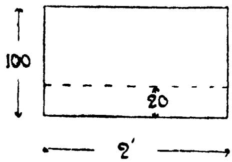


Fig. 16.

Force on the piston = Area × pressure per square inch = 1·5 × 144 × 100 = 21,600 lb.

Work done per stroke = force on piston × stroke.

Work done per stroke = 21,600 × 2 = 43,200 foot lb.

Cubic feet of steam used = area × stroke = 1·5 × 2 = 3 cu. ft.

Work done per cu. ft. of steam = $\frac{43200}{3}$ = **14,400 ft. lb.**

At the end of the stroke, the steam is exhausted at full pressure, carrying all its heat to waste.

Vertical lines on these diagrams represent lb. per square inch.

EXPANSIVE WORKING OF STEAM. Let us suppose now that we cut off the supply of steam from the boiler when the piston has moved half way along the cylinder, or at "half stroke." As the piston moves further along the cylinder, the steam will fall in pressure, and exert upon the piston a force which gradually diminishes until the end of the stroke is reached. The average or mean pressure must be found. What shape does the curve of pressure take in practice ?—this depends upon the conditions of working, such as keeping the cylinders well lagged with non-conducting material, and keeping it well drained of water. We shall assume that after cut off in this engine the pressure varies according to the simple law $p\ v$ = constant.

The area of the diagram of work may be found by a formula based upon the law $p\ v$ = constant. Now in this case the steam at cut off has a volume of 1·5 × 1 = 1·5 cu. ft., and at the end of the stroke its volume is 3 cu. ft., and the steam is said to have expanded to twice its original volume, and the **ratio of expansion** is said to be "two."

$$\text{Ratio of expansion, or Number of expansions} = \frac{\text{Final volume of steam}}{\text{Original volume of steam}}$$

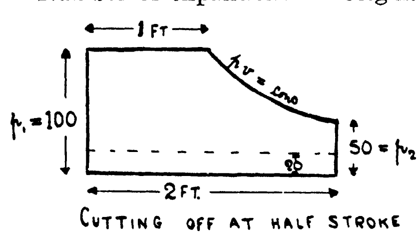


Fig. 17

Since $p_1\ v_1 = p_2\ v_2$

$100 \times 1 = p_2 \times 2$

p_2 = 50 lb. per square inch. (Fig. 17).

So that the final pressure is 50 lb. per square inch absolute, and the steam when exhausted carries much less energy to waste.

The mean pressure has been worked out here and found to be 84·7 lb. per square inch absolute, and the work done is 36,600 ft. lb.

Work done per cu. ft. of steam = $\frac{36{,}600}{1\cdot5}$ = **24,400 ft. lb.**

Now in the case of non-expansive working, the work done per cu. ft. of steam was only 14,400 ft. lb. Hence by working the steam expansively we have gained 24,400—14,400 or 10,000 ft. lb. of work per cu. ft. of steam supplied from the boiler, and the advantage of working the steam expansively is apparent.

The work done in the same cylinder is less, but the work done per cu. ft. if steam supplied, and therefore for the same fuel burned, is much more.

BACK PRESSURE. In the examples given, we have assumed that there is pressure on one side of the piston only ; but in practice there is always pressure on both sides of the piston. The pressure on that side of the piston which opposes its motion is called the back pressure. Suppose that in the examples given, there is a back pressure of 20 lb. per square inch absolute in each case. The work done against the back pressure must be subtracted, this work is represented by the area below the dotted line in the diagrams, and is $20 \times 1{\cdot}5 \times 144 \times 2 = 8{,}640$ foot lb.

Nett work done without expansion $= 43{,}200 - 8{,}640 = 34{,}560$ ft. lb.

Nett work done with expansion $= 36{,}600 - 8{,}640 = 27{,}960$ ft. lb.

$$\text{Work per cu. ft. in 1st case} = \frac{34{,}560}{3} = \mathbf{11{,}520\ ft.\ lb.}$$

$$\text{Work per cu. ft. in 2nd case} = \frac{27{,}960}{1{\cdot}5} = \mathbf{18{,}640\ ft.\ lb.}$$

The benefit of expansion is greater as the back pressure is reduced.

THE EFFECTIVE PRESSURE. In the example, the effective pressure acting on the piston in case 1, is 100 — 20, or 80 lb. per square inch. In case 2, the effective pressure at any part of the stroke is the distance measured from the top line and the curve, down to the dotted line.

THE MEAN EFFECTIVE PRESSURE is the constant pressure which if acting during the whole stroke, will perform the same work as the varying pressure actually does. In case 2, the mean effective pressure is $84{\cdot}7 - 20 = 64{\cdot}7$ lb. per square inch, and the work done is $1{\cdot}5 \times 144 \times 64{\cdot}7 \times 2 = 27{,}960$ ft. lb. which agrees with the value already given.

CYCLE OF OPERATIONS. Let a quantity of a substance be at a definite temperature, pressure and volume, and suppose we give it heat, thereby changing its temperature pressure and volume ; now let the substance do work by giving up heat, and suppose that it comes back again to its original state of temperature, pressure and volume, the substance is said to have passed through a cycle of operations. Now in converting energy from one form into another, there is always a loss, and the losses are great in converting heat into work. In the steam engine the coal on the fire grate

is the source of heat, and the condenser is that part of the cycle where the lowest temperature and pressure exist. The heat in the steam does work by falling from the temperature of the boiler to the temperature of the condenser. Thus the steam may be expanded down to a few pounds per square inch above the pressure in the condenser, its temperature being a few degrees above the temperature in the condenser. Hence it is the pressure in the boiler and the pressure in the condenser which **limits the number of expansions** of the steam, and hence the work done.

THE STEAM ENGINE CYCLE is as follows. One pound of feed water at a definite temperature is pumped into the boiler. In the boiler it is given sensible heat to raise it to the temperature of the steam. It is now given latent heat which changes it into the vapourous form. The steam is now admitted to the cylinder and does work by expansion; at the end of expansion the steam, now wet and at a low pressure and temperature is condensed back into water in the condenser. This pound of water has passed through a " cycle of operations."

THE INDICATOR is an instrument which draws a diagram showing the work done by the steam in the cylinder. From this

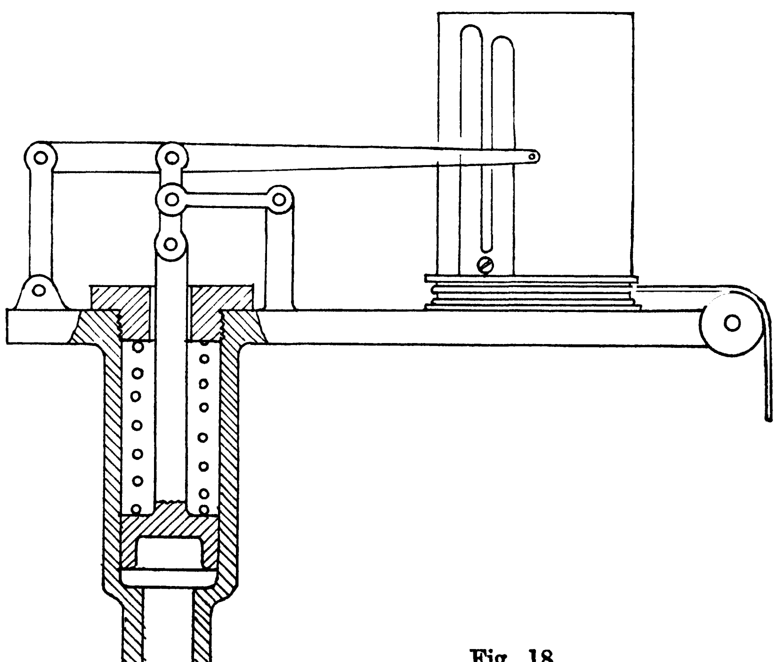


Fig. 18.

diagram, the mean effective pressure and the horse power of the engine can be calculated.

The instrument consists essentially of a small cylinder containing a piston subjected to the varying pressure in the engine cylinders. This pressure moves the small piston up and down against a spring. A spindle connects the piston to a system of small levers as shown in Fig. 18. A brass point on the end of the longer lever bears on a drum on which a special kind of paper is held by the clips shown. The drum contains an internal spring which tends to hold it in the position shown. A cord wrapped around the bottom of the drum is attached at its other end to a lever which is moved up and down by the engine crosshead. The drum therefore turns part of a revolution when the engine piston moves down and turns back again when the piston moves up. The point on the lever therefore draws a diagram which is a record of the pressure in the cylinder at any point of the up and down strokes of the engine.

HORSE POWER. Power is **rate** of doing work. One horse power is equivalent to 33,000 foot pounds of work per minute.

INDICATED HORSE POWER (I.H.P.). This is the power actually developed in the cylinders of an engine. The mean effective pressure is found from the indicator diagram, for both the up and down strokes, and the mean of these is taken.

The foot-lb. of work done per minute is divided by 33,000 to obtain the Indicated Horse Power, thus :

Let p = mean effective pressure, in lb. per sq. inch,
A = area of piston, in sq. inches,
L = length of stroke, in feet,
N = number of effective strokes per minute,

then :

total effective lb. of force pushing on piston $= p \times A$
Ft-lb. of work done in one stroke $= p \times A \times L$
Ft-lb. of work done in one minute $= p \times A \times L \times N$

$$\therefore \text{ I.H.P.} = \frac{p\,A\,L\,N}{33{,}000}$$

This is the general formula for calculating the I.H.P. of any type of reciprocating engine. For a steam engine, as every stroke is effective and there are two strokes to every revolution of the crank, the value of N for a steam engine is 2 × revs. per min. The value of N for a Two-Stroke Diesel engine (Single-Acting) is equal to the number of revs. per minute, and for a Four-Stroke Diesel engine (Single-Acting), it is half of the number of revs. per minute. Diesel engines are dealt with in Chapter VII.

Example; The piston of a single-cylinder steam engine is 9 inches diameter and the stroke is 12 inches. Find the I.H.P. developed

when the mean effective pressure is 50lb. per sq. in. and the speed 280 revs. per min.

$$\text{I.H.P.} = \frac{p\,A\,L\,N}{33{,}000}$$

$$= \frac{50 \times 11 \times 9^2 \times 1 \times 280 \times 2}{14 \times 33{,}000}$$

$$= 54.$$

The total I.H.P. of an engine with more than one cylinder, can be determined by first finding the I.H.P. for each cylinder, and then adding together.

BRAKE HORSE POWER. All the power developed in the cylinders is not transmitted to the shaft. Some of it is lost in friction at the rubbing surfaces of the various bearings. The brake horse power is the power actually given out by the shaft, and in a good modern steam engine, the brake horse power should be about 85 per cent. of the indicated horse power.

THE MECHANICAL EFFICIENCY of an engine is expressed as the fraction :—

$$\frac{\text{Brake horse power}}{\text{Indicated horse power}}$$

ECONOMY OF HIGH PRESSURE STEAM. The total heat of steam at 100 lb. per square inch is 1,189 B.T.U. per lb.; the total heat of steam at 200 lb. per square inch is 1,202 B.T.U. per lb. It is seen that the pressure is doubled by giving an extra 12 B.T.U. per lb. to steam at 100 lb. per square inch. The pressure increases much more rapidly than the total heat contents; with the values given in this example, we need supply $\frac{1202}{1186} = 1{\cdot}0109$ times the heat only, to raise the pressure from 100 to 200 lb. per square inch. This is one explanation of the economy of high pressure steam.

MULTIPLE EXPANSION. In the ordinary steam cylinder, the steam enters and leaves the cylinder by the same port or passage way. Now the steam as it enters the cylinder is at a high pressure and temperature. After doing work on the piston the steam is exhausted at a much lower pressure and temperature. The exhaust steam cools the walls of the port as it is discharged. At the beginning of the next stroke, the hot high pressure steam is brought into contact with the cooler walls of the steam port, and some of it is at once condensed into water. Now when steam is condensed into water, its volume is greatly diminished.

The steam which is condensed is at once replaced by more steam from the boiler until cut off takes place, and the consumption of steam and therefore of fuel is greatly increased. Instead of having merely to fill the cylinder up to the point of cut off with high pressure

steam, we have to supply a much larger volume. This condition is called **INITIAL CONDENSATION.** Now it can be easily understood, that the greater the difference between the temperature of the steam entering and the temperature of the steam leaving the cylinder, the greater will be the quantity of inlet steam condensed. Hence we must limit the temperature range per cylinder, or in other words, we must limit the ratio of expansion per cylinder. To attempt to expand steam from 200 lb. per square inch to 4 lb. per square inch in one cylinder would be a very uneconomical proceeding. For steam pressures up to about 100 lb. per square inch, two stage expansion is commonly used, and the engine is called the " two stage compound," and it generally has two cylinders. Steam is admitted to the first cylinder, called the high pressure cylinder, cut off at about half stroke, then exhausted after about half of its heat energy has been given up as work. This exhaust steam from the high pressure cylinder, is now admitted to the low pressure cylinder. During expansion in the first cylinder, the steam was reduced in pressure and greatly increased in volume, hence the low pressure cylinder must have a much larger volume than the high pressure cylinder. The remainder of the available heat in the steam is converted into work on the low pressure piston, and the steam is then exhausted to the condenser.

BY COMPOUND EXPANSION we really mean any number of expansions. When we say " two stage compound " we do not necessarily mean that the engine has two cylinders, but that the steam is expanded in two separate stages. A two stage compound engine may have one high pressure cylinder, and one low pressure cylinder ; or it may have one high pressure cylinder, and two low pressure cylinders working at the same pressure. For the same power, the one L.P. cylinder in the two cylinder engine must have the same total volume as the two L.P. cylinders of the three cylinder engine. In the case of very large marine engines only, three cylinders were used for two stage compounds. With three cranks a better turning effect was maintained. In the two stage expansion type, the steam is expanded to about 8 times its original volume.

IN THE TRIPLE EXPANSION engine, the steam is expanded in three stages, the engine generally has three cylinders, but it may have four. The steam pressure used varies from about 160 lb. per square inch to 200 lb. per square inch. The cylinder diameters are successively larger. If the engine has four cylinders, the two low pressure cylinders have the same total volume as one low pressure cylinder would have for an engine of the same power with three cylinders. In this type the steam is expanded to about 11 times its original volume.

THE QUADRUPLE EXPANSION expands the steam in four stages. It has four cylinders, and uses steam from about 200 lb. per square inch to 250 lb. per square inch. In this type the steam is expanded to about 12 to 14 times its original volume.

CHAPTER IV.

THE RECIPROCATING STEAM ENGINE. ESSENTIAL PARTS, FUNCTIONS, Etc.

THE RECIPROCATING ENGINE is one in which a reciprocating or " to and fro " motion is converted into a rotary motion. The essential parts of a reciprocating steam engine are :—**A CYLINDER** in which a piston works " to and fro " driven by the pressure of the steam. **A PISTON ROD** firmly secured into the piston, and passing through a steam tight arrangement called a **STUFFING BOX** and **GLAND** in the cylinder end. **A CROSSHEAD** secured to the other end of the piston rod, and having guide shoes which work upon **GUIDES** on the engine framing in order to keep the centre line of the piston rod always in line with the central axis of the cylinder. **A CONNECTING ROD,** freely jointed by the **TOP END PIN** to the crosshead at one end, and connected at its other end to the crank pin by means of the **BOTTOM END BEARING** or " crank pin bearing." **A CRANK SHAFT** which rotates in **MAIN BEARINGS.** The **CRANK** is an arm firmly secured at right angles to the shaft, and the **CRANK PIN** is also fixed at right angles to the crank. The length of the crank is the distance between the centre of the shaft and the centre of the crank pin. **A VALVE** or valves to admit steam alternately to each end of the cylinder, and to allow it to be exhausted at the end of the piston stroke. **SUITABLE VALVE GEAR** for controlling the action of this valve.

REVERSING MECHANISM to enable the engine to run ahead or astern. The conditions of service for a modern marine engine using high pressure steam, require the boilers to be supplied with fresh water feed, and the engine must be fitted with a **CONDENSER** in which the steam, after doing work in the cylinders, is condensed into water. This arrangement means that the same fresh water, with slight additions to make good the loss by leakage, is used over and over again.

IN THE CONDENSER the steam is condensed by coming into contact with the outer surfaces of tubes through which sea water is pumped by the **CIRCULATING PUMP. AN AIR PUMP** is needed to extract the air and the condensed water from the condenser. Air comes into the condenser with the steam ; but it cannot, like the steam, be condensed, and it must be removed to maintain a high vacuum or a region of low pressure in the condenser.

FEED PUMPS are needed to force the condensed water back into the boiler.

THE SCREW PROPELLER is invariably used, and this is firmly secured to the **TAIL END SHAFT** which passes through a **STERN TUBE** and a watertight arrangement called a **STERN GLAND** into the tunnel in the inside of the ship. **THE THRUST SHAFT**

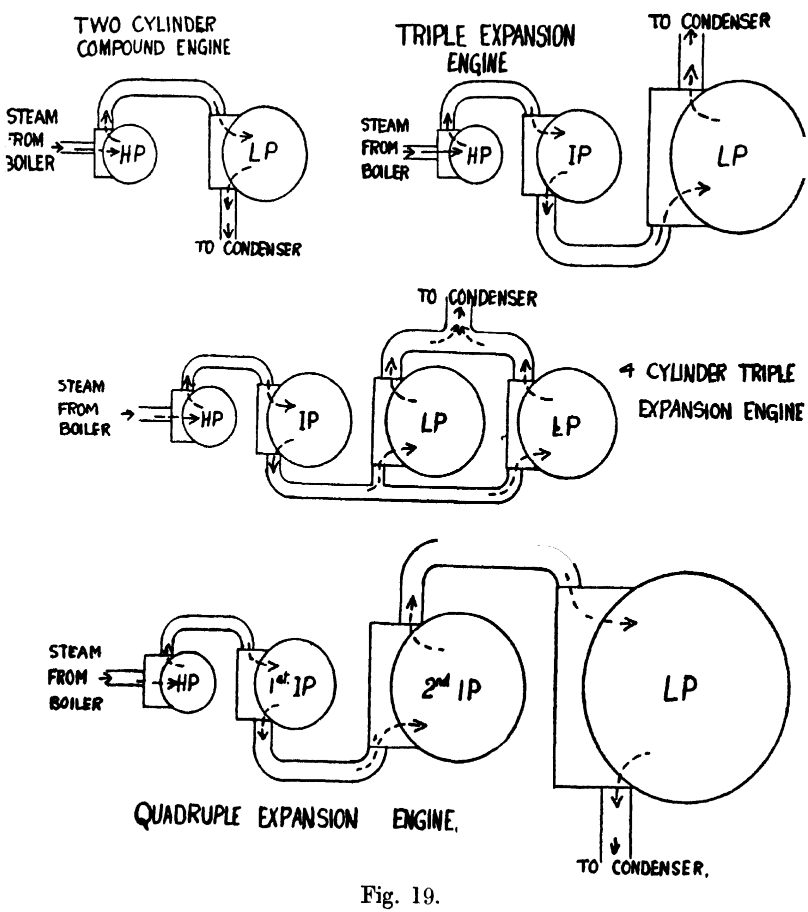


Fig. 19.

and the bearing in which it works called the **THRUST BLOCK,** is the arrangement whereby the thrust of the propeller is applied to the hull of the vessel. A steam engine may have one cylinder only, or it may have several cylinders arranged in series, the steam entering the first of the series at the maximum boiler pressure and

passing through the others in succession at pressures proportionally less as the volumes of the cylinders increase. The first form is a simple engine, and it has only one stage of steam expansion. The second form is known as a compound engine; there may be two cylinders and two stages of expansion, three cylinders and three stages, or four cylinders and four stages. This has been treated in the previous chapter. For the moderate power required in the mercantile marine, the three stage compound, generally called **THE TRIPLE EXPANSION ENGINE** having 3 cranks at 120° to each other, has for many years been the favoured arrangement. Fig. 19 shows the cylinder arrangements for the different types.

In the two cylinder compound the first cylinder of the series is called the high pressure (H.P.) cylinder, and the last the low pressure (L.P.) cylinder. The **CYLINDERS INTERPOSED** between the H.P. and the L.P. cylinders in triple and quadruple expansion engines, are called **INTERMEDIATE CYLINDERS. THE STROKE** of the piston, which is twice the length of the crank is the same for all the cylinders. The diameters of the cylinders increase from H.P. to L.P. An average value for the ratios of the cylinder volumes for a triple expansion engine is as 1 : 2·64 : 7, and for a quadruple engine as 1 : 2 : 4·32 : 9. This means that the I.P. cylinder of a triple expansion has a volume 2·64 times that of the H.P. cylinder, and that the L.P. cylinder has a volume 7 times that of the H.P. cylinder.

THE DIMENSIONS OF THE ENGINE depend upon the horse power required. A triple expansion engine having the H.P. cylinder 25 inches diameter, the I.P. 41 inches diameter and the L.P. 66 inches diameter might be suggested as an average size, the stroke of each engine being 4 feet, and with a boiler pressure of 180 lb. per sq. inch, this engine should develop about 2,200 horse power at 70 revolutions per minute. It should propel a vessel of 8,000 tons displacement at 11·5 knots on a consumption of 34 tons of coal per day for the main engine only, or about 38 tons per day for all purposes, the latter figure depending on the number of auxiliary engines working. Marine reciprocating engines are often rated as being of a certain **NOMINAL HORSE POWER** (N.H.P.), and candidates for certificates of competency for 1st class Engineer, must have performed their sea service with steam engines of not less than 99 N.H.P. The N.H.P. may be obtained by dividing the sum of the squares of the cylinder diameters by 26, and by this rule the N.H.P. of the engine suggested would be about 350. It is obvious that the N.H.P. gives little or no indication of the power the engine can develop. The Ministry of Transport now use a rule which takes into account the L.P. cylinder diameter, the stroke, the boiler pressure and the area of the heating surface in the boiler, to determine the N.H.P. Working by this rule we get a number which has no relation to the indicated horse power of the engine. Nominal

horse power is used as a very rough standard for comparing the sizes of reciprocating engines, and the system is not very satisfactory.

THE PASSAGE OF THE STEAM from the boiler through the engine to the condenser and back to the boiler as the feed water may be traced as follows :—Take the case of a triple expansion engine taking steam from the boilers at 180 lb. per sq. inch. Steam from the **MAIN STOP VALVE** on the boiler passes into the **MAIN STEAM PIPE,** passes through the **INTERMEDIATE OR ENGINE STOP VALVE** into the **H.P. RECEIVER** or **STEAM CHEST.** A steam chest is that part of the cylinder casting in which the slide valve works. To induce a steady flow of steam from the boiler to this chest, it is reasonable to expect the pressure to be slightly less here than at the boiler. The H.P. receiver pressure gauge may show a pressure of 175 lb. per sq. inch. Steam is admitted to the **H.P. CYLINDER** by the action of the **H.P. SLIDE VALVE,** which supplies steam from the beginning of each stroke until about 0·6 of the piston stroke has been completed. The **VALVE NOW CUTS OFF** the steam, and the piston is moved for the remainder of the stroke by the expansive action of the steam. At about 0·9 of the stroke, when the pressure of the steam has fallen to about 110 lb. per sq. inch, the slide valve uncovers the **EXHAUST PASSAGE** or port into which the expanded steam is " released " and passes into the **RECEIVER** of the **INTERMEDIATE** engine. The volume of this receiver is thus connected up with the volume of the H.P. cylinder during exhaust, again increasing the volume to be occupied by the steam, and a further fall in pressure takes place. The pressure in the intermediate receiver may be taken as about 65 lb. per sq. inch, and this is the " back pressure " against which the H.P. piston has to work. Further, the H.P. slide valve must now close the exhaust from the H.P. cylinder before the return stroke is completed, to retain some steam in the cylinder for " cushioning " and thus bringing the moving parts to rest quietly as the engine passes the dead centre. The reciprocating parts of each engine weigh several tons, their velocity is great and they must be brought to rest without shock.

Steam is now admitted from the I.P. receiver to the **I.P. CYLINDER** by the I.P. slide valve, which cuts off the steam at about 0·65 of the stroke. After expansion in this cylinder the steam has fallen to about 30 lb. per sq. inch, and it is released at 0·9 of the stroke, and passes through the **I.P. EXHAUST PORT** into the **L.P. RECEIVER** where the pressure falls to about 15 lb. per square inch. This pressure is the back pressure against which the I.P. piston works. The L.P. slide valve admits steam to the **L.P. CYLINDER,** cut off takes place at about 0·65 of the stroke, further expansion takes place and the steam is **RELEASED TO THE CONDENSER** at a pressure of about 10 lb. per sq. inch absolute, or 5 lb. per sq. inch below the pressure of the atmosphere. The

pressure in the condenser is generally about 2·5 lb. per square inch absolute (25 inches of vacuum), but the back pressure on the L.P. piston will be about 4 lb. per sq. inch. The **EXHAUST STEAM** now passes through the eduction or exhaust pipe and comes into

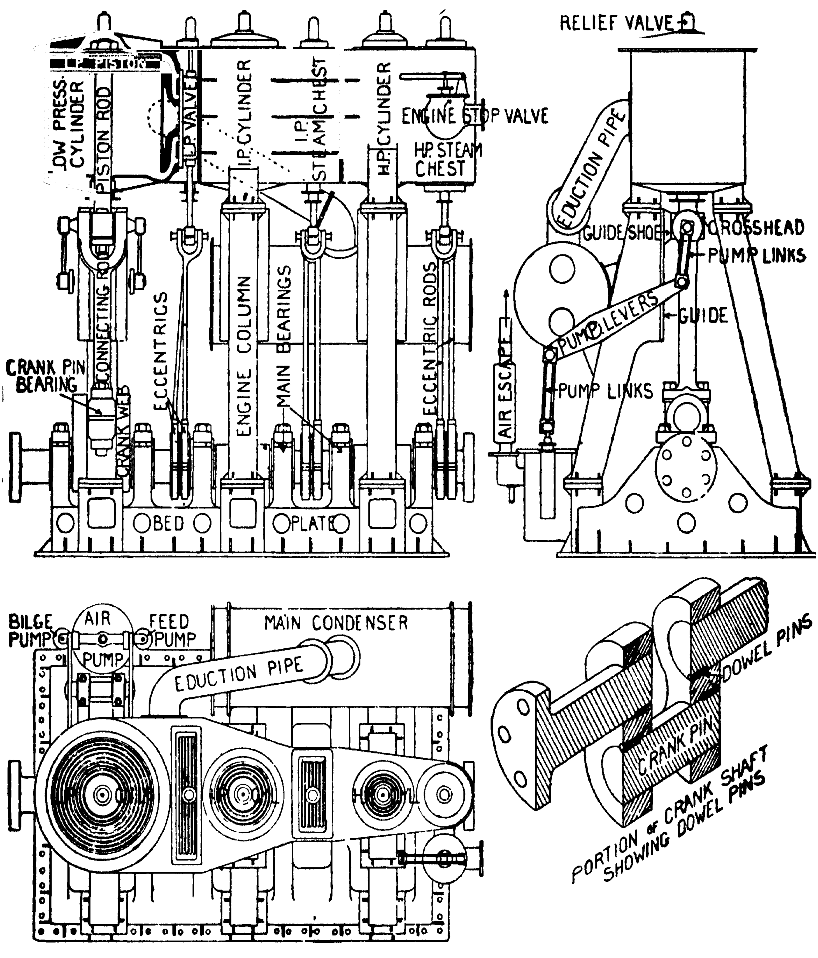


Fig. 20.

contact with the external surfaces of the tubes in the condenser, when it gives up its latent heat to the sea water passing through the tubes, and falls to the bottom of the condenser as water at about 130° F. The condensed water runs into the suction end of the vertical **AIR PUMP,** and it is delivered by this pump into a

chamber called **THE HOT WELL** together with the air and water vapour from the condenser. The air and vapour escape by a pipe to the atmosphere; the water passes through a **FILTER** which extracts any oily matter present, and on to the suction of the **FEED PUMPS.** The feed pumps return the water to the boiler, generally through a **FEED HEATER,** whereby its temperature is raised to about 220° F.

A BRIEF SUMMARY of these operations may be useful:—

Steam at 180 lb. per sq. inch passes from the main steam pipe into the H.P. receiver, when it is admitted to the H.P. cylinder; doing work on the H.P. piston it falls in pressure and is then exhausted to the I.P. receiver at about 65 lb. per sq. inch. From the I.P. receiver the steam is admitted to the I.P. cylinder, where it does work on the I.P. piston, its pressure being further reduced, then it is exhausted to the L.P. receiver. From the L.P. receiver the steam is admitted to the L.P. cylinder, does work on the L.P. piston with further loss of pressure, then it is exhausted into the condenser. It is arranged that each cylinder develops about the same horse power. In the condenser the steam is condensed into water. The air pump takes the air and water and delivers them into the hot well. **THE HOT WELL** is a chamber into which the air pump delivers the condensed water, and from which the air escapes into the atmosphere. From the hot well the water passes through a filter into the feed pumps. The feed pumps force the water through a heater into the boiler.

Fig. 20 shows the arrangement of a triple expansion engine diagrammatically, and the position of the important parts is indicated.

CYLINDERS. Each cylinder and its receiver or steam chest forms one casting and is made of good quality cast iron, the bottom cover being part of the casting. The piston rod stuffing boxes are separate castings, and are secured to the bottom cover by studs and nuts. Feet are cast at the lower end of the cylinder barrel for attachment to the engine columns.

CYLINDER LINERS. The H.P. cylinder barrel is generally fitted with an internal liner of hard close-grained cast iron, capable of taking and retaining a highly polished surface. This liner may be easily and cheaply renewed when necessary. On account of the high pressure and temperature in the H.P. cylinder, the wearing of the liner and the piston rings may be considerable. Liners are not generally fitted in the I.P. and L.P. cylinders, but the metal is made thicker than is necessary for strength; this permits the cylinder to be rebored when worn, and a new piston, slightly larger than the original one, fitted. When the working surface of a cylinder becomes " scored " or worn into grooves, or if the wear is such that the cylinder becomes slightly oval instead of remaining circular,

steam passes from one side of the piston to the other, with loss of efficiency. Hence the importance of keeping the working surface in perfect condition.

CYLINDER RELIEF VALVES should be fitted to both top and bottom covers of the cylinders. These are spring loaded valves. Should water be present in the cylinder and imprisoned between the moving piston and the cover, this valve will open, and prevent damage to the cylinder. Each steam chest is also fitted with a relief valve, set to open at a pressure slightly greater than the working pressure in the chest.

CYLINDER DRAIN COCKS are fitted to each end so that the cylinders may be drained of any accumulation of water.

THE LAGGING of cylinders with non-conducting materials is important. Silicate of cotton is used to cover the cylinders externally, and the loss of heat by radiation is greatly reduced. A thin sheet iron casing bent into the correct shape round the cylinders, holds the lagging in position.

CYLINDER COVERS and steam chest covers are hollow castings of cast iron, the upper and lower parts being connected by strong internal webs. The upward load on the cover of the H.P. cylinder at the beginning of the stroke is about 40 tons. The covers are secured to the flange of the cylinder casting by mild steel studs and nuts, asbestos tape being used to make a steam tight joint.

PISTONS may be castings of cast iron or mild steel. When of cast iron, they are made hollow and of considerable depth ; the bottom surface is flat, the upper surface slightly conical, internal radial webs connecting and stiffening the two parts. Cast steel pistons are not made hollow. They are cone shaped for stiffness, and are much lighter than cast iron pistons, although cast iron pistons are mostly used in the merchant service. **A TAPERED HOLE** is bored through the centre of the piston for the reception of the tapered end of the piston rod. The end of the piston rod is screwed and fitted with a nut, which when screwed down into the top of the piston, holds it firmly on the tapered part of the rod. The piston is machined to fit into the cylinder easily.

PISTON PACKING RINGS. The piston must work steam-tight in the cylinder, and packing rings generally called " piston rings " are fitted into annular grooves machined in the piston. Many forms of packing rings have been devised, but in principle they are all similar. The simplest form used for main engine cylinders up to 45 inches diameter, is a plain ring of hard close-grained cast iron, having a square section of from $\frac{1}{2}$ inch to $\frac{7}{8}$ inch. Three or four of these rings are necessary in each piston. They may be fitted into separate grooves, or two rings may be fitted into one groove. The rings are machined to a diameter about $\frac{1}{2}$ inch greater than the cylinder diameter, pieces are cut out so that the rings will fit into the cylinder, the cut ends of the rings almost touching. In

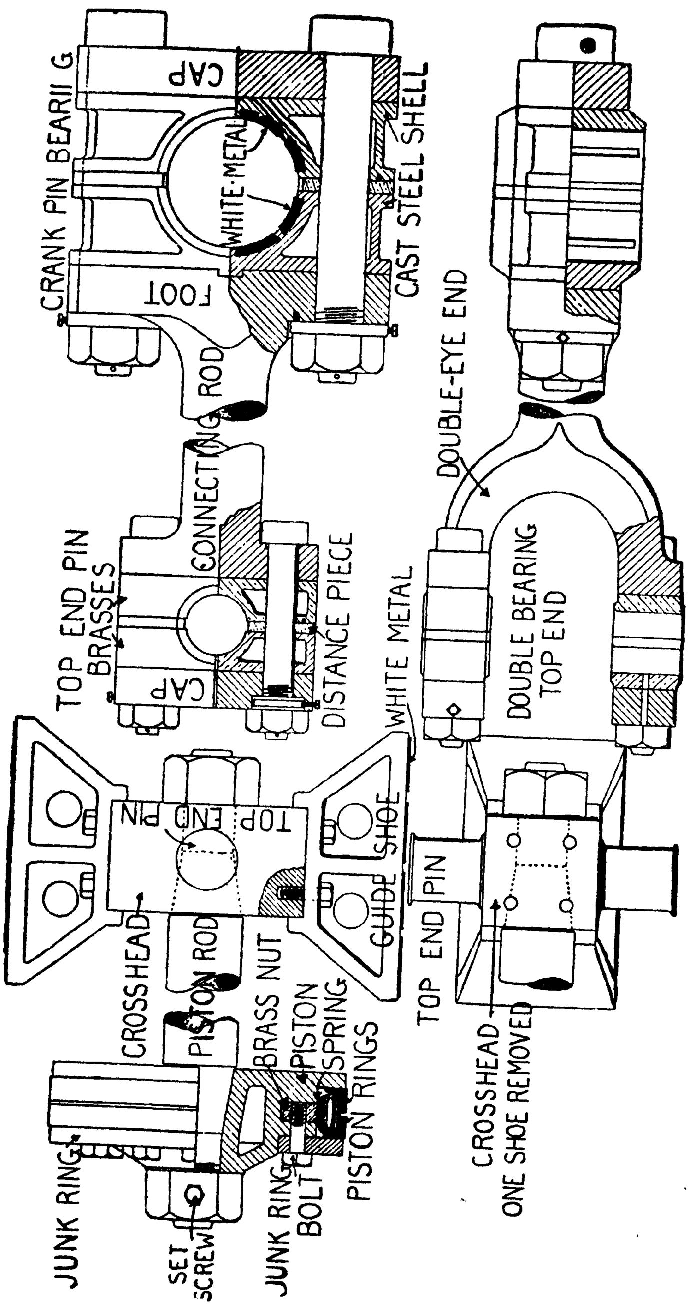

CRANK PIN BEARII G
CAP
FOOT
WHITE·METAL
CAST STEEL SHELL
CONNECTING ROD
DOUBLE-EYE END
TOP END PIN
BRASSES
CAP
DISTANCE PIECE
WHITE METAL
DOUBLE BEARING
TOP END
TOP END PIN
CROSSHEAD
PISTON ROD
BRASS NUT
GUIDE SHOE
TOP END PIN
PISTON
SPRING
PISTON RINGS
CROSSHEAD
ONE SHOE REMOVED
JUNK RING
SET
SCREW
JUNK RING
BOLT

Fig. 21.

the case of pistons of moderate diameter, say up to about 24 inches, these rings are often merely " sprung " over the piston into their grooves. This type of ring is called the " Ramsbottom " ring. The rings must fit freely in their grooves, and be able to expand outwards, exerting a slight radial pressure on the cylinder. It is, however, desirable that the rings should be accessible without taking the piston out of the cylinder. This is done by machining the upper part of the piston to a smaller diameter, and fitting it with a separate ring of cast iron, called the **JUNK RING.** The packing rings are fitted between the bottom flange of the piston and the junk ring, see Fig. 21. The junk ring is secured to the piston by mild steel **JUNK RING BOLTS,** which screw into brass nuts fitting loosely into recesses cast in the piston.

A very common form of piston ring packing consists of two cast iron rings of angle bar section. These rings are machined and cut as already described. A steel spring ring, having helical coils alternately vertical and circumferential, fits in the recess between the inner parts of the two rings. The vertical coils press the rings against the piston flange and the junk ring, the circumferential coils press the rings against the walls of the cylinder, see Fig. 22.

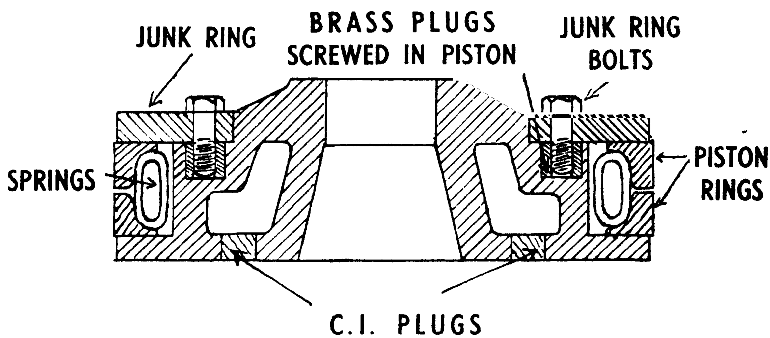


Fig. 22

PISTON ROD. This is a mild steel forging, tapered at one end to fit the hole bored in the piston. The taper should not be less than ¾ inch per foot otherwise there is danger of splitting the piston, or it will become so tightly wedged as to be very difficult to withdraw when necessary. The best practice is to make the diameter of the larger end of the taper about ½ inch less than the body of the piston rod, to taper the end for about one-half of the piston depth, and to machine the remainder parallel. The shoulder so formed allows the rod to be turned true when worn, without encroaching on the tapered portion ; the taper should be about 3 inches per foot, and the rod is in consequence very readily withdrawable from the piston. See Fig. 21. The extreme end of the rod is screw cut with a vee thread, about four threads per inch, to take the piston rod nut. Some locking device, such as a set screw or a lock " plate," must be

fitted to ensure the nut will not slacken back when the engine is at work. The form of the lower end of the piston rod depends upon the type of crosshead employed.

CROSSHEAD "SINGLE BEARING TOP END." The lower end of the piston rod is forged to form a rectangular block, and this block or crosshead is machined to form a pocket which accommodates the " top end " or crosshead pin brass. **THE TOP END PIN** is secured, by shrinking, into the " double eye " end of the connecting rod. There is only one " pair of brasses," i.e., top half and bottom half, in this arrangement, but the bearing is not easy to adjust, and it is not often employed in modern marine engines. It is, however, the general type used for small engines. The bearings into which this pin fits are generally bronze, and in some cases lined with white metal.

CAST IRON SHOES are attached to the crosshead by flanges and tap bolts. The guide shoe which takes the thrust of the connecting rod when running ahead is faced with white metal, but the astern shoe is not always so faced. Sometimes only one shoe is employed and this is convenient as it results in an " open fronted " and accessible engine, but the guide surface for astern running is small, and difficulty may be experienced in running full speed astern for any considerable time due to overheating of these astern guides.

Attention should be drawn to the fact that the thrust of the connecting rod on the down stroke of the engine and its pull on the up stroke is always on one guide for one direction of rotation. An engine, driving a right handed propeller, revolves from port to starboard over the top centre when running ahead. The load is then entirely on the port guide and shoe. If the ship has a slight list to port, the lubricant is retained on the guide surfaces and the guides " run " better.

CROSSHEAD "DOUBLE BEARING TOP END". The lower end of the piston rod is machined to the same form as the end secured to the piston, and it fits into a rectangular block of mild steel. This block or crosshead, has two pins forged on it, whose axes are perpendicular to the central axis of the piston rod. These are the crosshead or " top end " pins. Two sets of bearings are required, these being secured to the upper end of the connecting rod. The arrangement is shown in Fig. 21. These bearings or " brasses " are easy to adjust, and if the piston rod and connecting rod should become " out of line," this is readily corrected by putting a liner of the necessary thickness between the lower half of one bearing and the connecting rod end.

The guide shoes are secured to the crosshead, as in the "single top end" type.

GUIDES are separate castings of iron secured to the columns by bolts. They are planed and scraped to a true surface, and shallow grooves or shallow circular recesses are sometimes made

in the surface to retain the lubricant and impart it to the shoe. The ahead guide is usually hollow and connection is made to the water service system so that this shoe is kept cool by sea water circulation.

An oil box is attached to the lower end of the guide, and a muntz metal comb attached to the guide shoe dips into this box on each stroke and effects the lubrication.

CONNECTING ROD. This is a mild steel forging having a double eye end at the upper end and a flat foot at the lower end to which is attached the **CRANK PIN BEARINGS,** more often referred to by engineers as the " bottom end." The bearings consist of shells of cast iron, or cast steel, lined with white metal which forms the actual bearing surface. A mild steel cap is fitted below the bottom half bearing and bolts pass through the cap, the bearings and the connecting rod foot. The arrangement is clearly shown in Fig. 21.

THE CRANK SHAFT. All parts of this important shaft are made of mild steel, and in modern practice the shaft is always "built up." The crank shaft of a triple expansion engine consists of three exactly similar and interchangeable sections, each section being made up of two crank webs into which the other ends of the shafts are secured by shrinking, and a crank pin, shrunk into and connecting the webs.

Holes are drilled, half in the web and half in the shaft, and into these holes **DOWEL PINS** are tightly driven. Dowel pins are a precaution against slipping of the crank round the shaft. They are fitted to the shaft and the crank pins, they are about 1¼ inches diameter and their length is equal to about half the diameter of the shaft. A small groove, to let air escape from the hole when the pin is being driven in, must be cut in the dowel pin. Considerations of strength would not require that each section of shaft should be the same size, because only the after section transmits the full power of the engines. By making each section similar, one spare section need only be carried on board ; or in the event of no spare section being carried, should defects develop in the after section, then the forward section may take its place and the engine worked with two cylinders.

THE CRANK SHAFT is supported by, and revolves in six bearings called the **MAIN BEARINGS.** These are cast iron or cast steel shells lined with white metal and fitted into pockets cast in the engine bedplate. The bearings are held down in place by mild steel caps, and heavy mild steel bolts and nuts.

THE BEDPLATE is a casting of either cast iron or mild steel, made in two or three sections bolted together. It carries the crank shaft, and is the foundation plate to which the bottom flanges of the engine columns are bolted. The bedplate rests on cast iron chocks of a thickness necessary to bring the crank shaft in line

with the thrust shaft. It is held down by numerous "**HOLDING DOWN" BOLTS** which pass through the flange on the bedplate, through the chocks and through the tank top.

THRUST SHAFT. The length of shafting immediately aft of the crank shaft and coupled to it, is called the thrust shaft. This shaft has from about 5 to 8 collars, depending on the power transmitted, machined on it, the collars being about 1·5 times the diameter of the shaft. Each collar is about $\frac{1}{4}$ of the diameter of the shaft in thickness, and the space between the collars is about $\frac{1}{3}$ of the diameter of the shaft. The thrust shaft transmits the propeller thrust to the thrust block.

THE THRUST BLOCK is the important bearing in which the thrust shaft rotates, and it imparts the thrust by means of the thrust seating to the tank top and thus to the hull. The block is of cast iron, it is a long casting of hollow box form, rectangular in plan, see Fig. 23. The inner bottom of the block is formed so

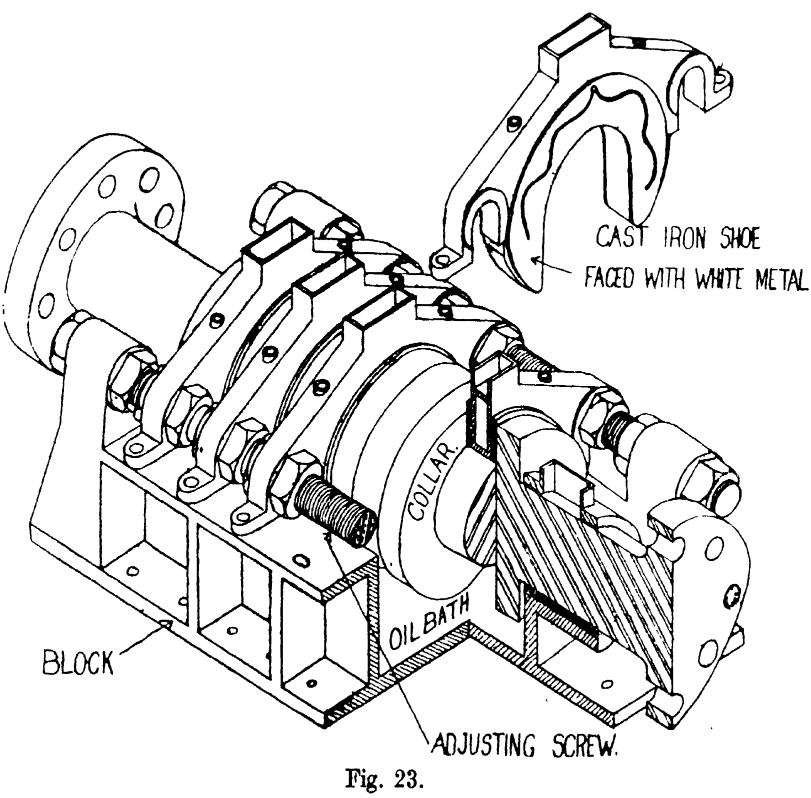


Fig. 23.

as to hold a considerable quantity of oil, into which the collars of the thrust shaft dip. The thrust block is firmly bolted down to its seating by bolts through the bottom flange, the seating being riveted to the tank top.

To relieve the holding down bolts of shearing stress, angle bar chocks butting against the forward and the after end of the thrust block, are riveted to the seating. The thrust block has a bearing at each end, lined with white metal, in which the shaft runs. Two heavy rods of muntz metal, 2 or 3 inches diameter, screwed their entire length, are fitted one on each side of the block and secured into bosses cast on the outside of the block. These rods are parallel to the shaft and fitted with brass nuts.

THE THRUST SHOES. Fitting into the spaces between the collars on the thrust-shaft, and occupying the full width of the thrust block, are the thrust shoes. These are of cast iron, shaped like horse shoes, and they are faced on their flat sides with white metal, see Fig. 23. The thrust shoes have lugs which project over the sides of the block and engage the screwed rods, the nuts on which, are placed so as to keep the shoes in their correct position. Adjustment of the shoes in a fore and aft line can be effected by these nuts. The collars on the thrust shaft transmit the propeller thrust to these shoes, which in turn transmit it to the thrust block and hence to the hull of the ship. No thrust is transmitted to the crank shaft, and the thrust shoes must be so adjusted that there is clearance between the crank webs and the ends of the main bearings. Ahead thrust is taken up between the forward side of the collars on the thrust shaft and the after face of the thrust shoes, the other face of the shoe taking the thrust when running astern. Thrust shoes are cast hollow, and sea water circulates through them.

THE MICHELL THRUST is a special type of thrust block, in which the thrust shaft has one collar only. The thrusting force is transmitted by the collar to a number of kidney shaped pads, faced with white metal on one face, and having a pivot on the other face which allows the pads to move through an exceedingly small angle. The shaft collar dips into the oil in the bottom of the thrust block, and carries oil round as it rotates ; the oil is thus forced between the face of the shaft collar and the pad, which, tilting slightly on its pivot, allows a wedge shaped film of oil to be maintained between the rubbing surfaces. In short, the face of the shaft collar and the face of the pad are not quite parallel, and the oil enters at the leading edge of the pad, where the clearance (though very small) between the collar and the pad, is greater than the clearance at the other end of the pad. Thus the wedge shaped film of oil is easily maintained. Now the purpose of lubrication is to maintain a film of oil between the rubbing surfaces, and prevent them from coming into metallic contact. In the ordinary type of thrust, previously described, the shoes are kept parallel to the

face of the shaft collars and scrape the oil from the faces of the collars, and it is more difficult to keep the rubbing surfaces apart. In the Michell thrust pressures up to 300 lb. per square inch may safely be carried; whereas as in the ordinary type, 70 lb. per square inch is about the limit. Hence one collar in the Michell thrust can replace a number of collars in the ordinary thrust, and the power lost in friction is much reduced. The Michell thrust is now extensively used in all types of marine engines.

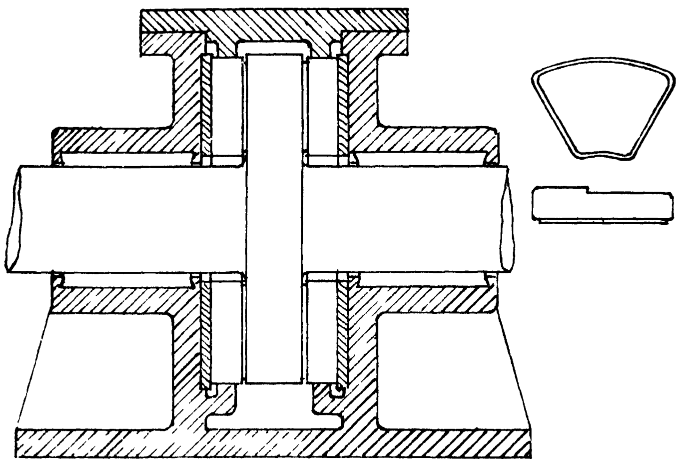
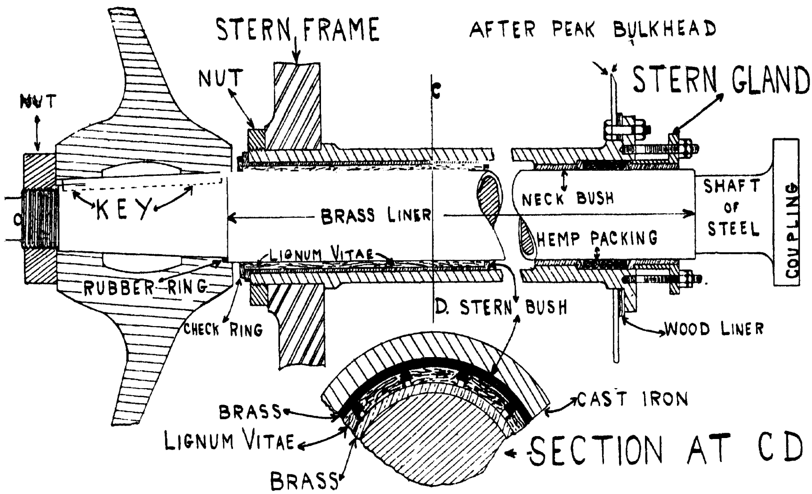


Fig. 24.

INTERMEDIATE OR TUNNEL SHAFTING. The lengths of shafting between the thrust shaft and the propeller or tail end shaft, constitute the tunnel shafting. The tunnel shafts run in bearings which are lined with white metal in the bottom halves only. The top half of the bearings is a light casting of cast iron, cored out to hold a block of solid lubricant. The tunnel shaft bearings are supported on pedestals formed of plates and angle bars, and of the correct height, and these pedestals are firmly riveted to the tank top.

PROPELLER SHAFT is sometimes called the "tail end" shaft. It is a mild steel forging of a length sufficient to pass from the inside of the ship, where it is coupled to the last section of the tunnel shafting, to the outside where it is secured to the propeller. It passes through the stern tube wherein the necessary bearing surfaces for the shaft to revolve on are arranged. The outboard end of the shaft is tapered for a distance about 2½ times the shaft diameter, the taper generally being 1 inch per foot. A key, with semi-circular ends, is sunk into this tapered part for its entire length. The boss

of the propeller is bored out to make an accurate fit on the tapered shaft, and the key-way is cut to fit the key closely on its sides, but clearance is allowed over the top of the key to ensure the propeller



LONGITUDINAL SECTION OF STERN TUBE.

Fig. 25

boss is fitting on the taper. A vee thread is cut on the outermost end of the shaft. The pitch is about 4 threads per inch, a left hand thread is used for a right hand propeller. Some locking device, such as a large pin through the end of the shaft behind the nut is provided to prevent the nut from slacking back. See Fig. 25.

A BRASS LINER OR SLEEVE about $\frac{3}{4}$ inch thick is fitted on the shaft, extending from the forward end of the propeller boss to within about one foot of the coupling. This liner is secured by shrinking, or it is forced on to the shaft by hydraulic rams.

STERN TUBE is a casting of iron about 2 inches thick, in which the propeller shaft revolves, and it must be very effectually secured to the structure of the ship. Its outer end is machined to fit very accurately the hole bored in the boss of the stern frame, through which it is passed from inboard. A flange, cast on the tube, fits against the forward side of the stern frame and a large circular wrought iron nut on the after side securely clamps the tube in positon. The stern tube has a large flange cast on its forward end and this is bolted to the forward side of the after peak bulkhead. The stern tube is put into position from inside the ship.

A long brass tube called the **STERN BUSH** is forced into the after end of the stern tube, and this bush holds the **LIGNUM VITÆ** which forms the bearing surface on which the brass liner on the tail shaft rotates.

THE LIGNUM VITÆ is made in long strips, which are dove-tailed into grooves cast in the bush, and extending the full length of the bush. The wood strips are kept in place fore and aft, by an inwardly projecting flange at the forward end, and a flat brass ring at the after end, this ring being fastened to the end of the stern tube by screws. See Fig. 25.

The strips are about 3 inches broad circumferentially and $\frac{7}{8}$ inch thick, spaces about $\frac{1}{2}$ inch broad are arranged between the strips to allow the passage of sea water necessary for lubrication. A stuffing box and gland is arranged at the forward end of the stern tube to prevent the ingress of water into the ship. **THE STERN GLAND** is packed with hemp packing, and it is always slackened back sufficiently, when the engine is running, to allow a small quantity of water to pass through into the after well. In this manner a gentle circulation of water is maintained through the tube, and the engineer satisfies himself, by noting the temperature of the issuing water, that the shaft is running satisfactorily.

LIGNUM VITÆ provides a fairly satisfatory bearing for the propeller shaft although the wear down may be rapid and the friction loss somewhat great. It is required that **PROPELLER SHAFTS** be withdrawn for **EXAMINATION ONCE IN TWO YEARS** and on these occasions the lignum vitæ is renewed, if necessary. To ascertain the amount the shaft has worn down a small wedge of wood, or copper, is used between the top of the shaft and the outer end of the stern bush. If the wear down is in excess of $\frac{5}{16}$ inch it is usually deemed advisable to renew the lignum vitæ or at least to renew the bottom half of it.

Some vessels are fitted with propeller shafts lubricated by means of oil. The stern bush is lined with white metal and there is no liner on the shaft. The stern tube is kept filled with oil from a service tank in the shaft tunnel, and to prevent oil from leaking out at the after end, or water being admitted, a special gland is fitted here. This consists essentially of a circular box of channel section, secured to the forward side of the propeller boss. The box contains a ring faced with white metal, and which is forced outwards against the end of the stern tube by means of helical springs. The arrangement is **CEDERVAL'S PATENT STERN TUBE,** but other manufacturers have adopted the idea. When correctly fitted the "wear down" is a very small amount, even after several years' running.

The tail end shaft is subjected to bending in addition to the torque which it transmits. It is subjected to severe impact when the vessel is racing in the ballast condition. On this account it is liable to develop flaws, also on account of the presence of sea

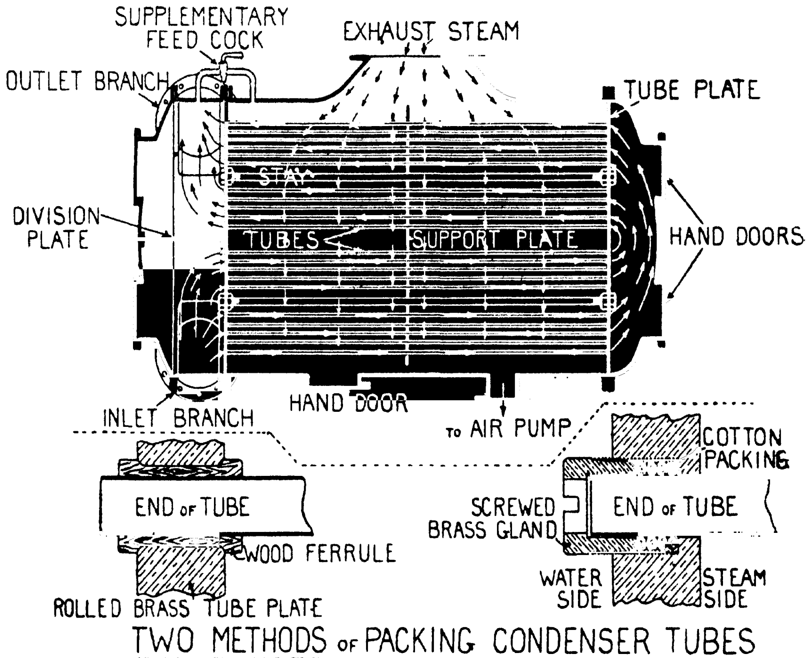


Fig. 26

water, the shaft may suffer by corrosion, hence the importance of frequently "drawing in" the shaft for examination.

WITHDRAWAL OF PROPELLER SHAFT. The coupling bolts of the aftermost length of tunnel shafting are removed, and this piece of shafting is rolled to one side. The packing is removed from the stern gland and the gland is replaced. The coupling of the propeller shaft is shored from the end of the stern tube by baulks of timber. The necessary tackle is hung up under the counter of the ship and attached to the propeller blades. The propeller nut is now "started" by blows from a hammer and slackened back a few turns. Heavy wedges are now driven in between the propeller boss and the stern tube to "start" the propeller off the taper of the shaft. When once started the propeller nut may be removed and the shaft pulled inboard by tackle in the tunnel.

COUPLING BOLTS are the bolts which fasten the couplings of the shafts firmly together. They are a driving fit in the holes of

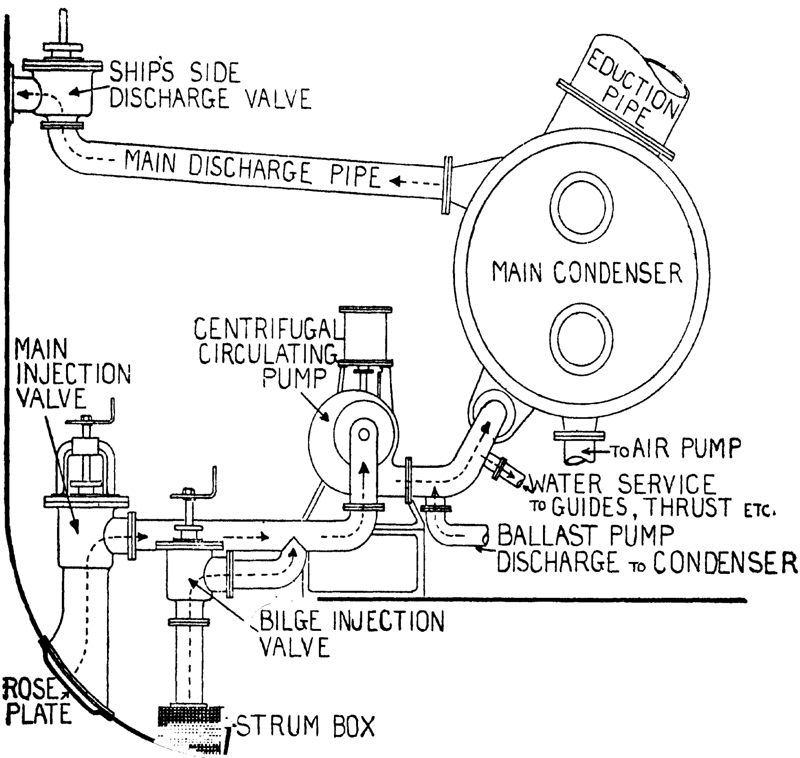


DIAGRAM OF MAIN CONDENSER CONNECTIONS

Fig. 27.

the coupling, and are fitted with split pins to prevent the nuts slacking back. These bolts are made of mild steel.

THE CONDENSER AND ITS CONNECTIONS. The condenser is the chamber in which the steam is condensed after doing work in the engines. Its purpose is three-fold, firstly to reduce as far as possible the back pressure on the piston of the L.P. engine, and so enable this engine to develop greater power; secondly to enable the steam to be expanded in the L.P. cylinder to a lower pressure than would be possible if the steam was exhausted into the atmos-

phere; and thirdly to ensure feed water for the boilers, uncontaminated by any solid matter in solution.

In its modern form, the condenser consists of a cylinder of mild steel plates having flanges formed of angle bars at each end; to these flanges are bolted the **TUBE PLATES.** The tube plates are discs of rolled brass about 1 inch thick, see Fig. 26, and they are perforated by a large number of holes about $\frac{3}{4}$ inch diameter, through which the tubes pass. Small stuffing boxes, with screwed glands, are arranged for each tube to prevent leakage of sea water. Cast iron chambers, called **WATER CHAMBERS,** are bolted to the tube plates at each end. One of these chambers has a horizontal division plate cast on, which divides the tubes into two nests or "boxes," and from below this division plate a pipe goes to the delivery connection of the circulating pump; from above this division plate a pipe goes to the **OVERBOARD DISCHARGE.**

THE CIRCULATING WATER is delivered by the circulating pump to the water chamber, passes through the lower nest of tubes to the other water chamber, then through the upper nest of tubes, and finally through the discharge overboard. The arrangement is called a "two flow" surface condenser and it is the usual arrangement. An engine of 2,200 I.H.P. would require about 1,000 tubes altogether, each being about $12\frac{1}{2}$ feet long. **THE TUBES** used are about $\frac{1}{16}$ inch thick, and may be of brass or bronze; in the best modern practice tubes are now made of a copper nickel alloy. The condenser is arranged with a large opening at the top by which the exhaust steam enters, and a smaller opening at the bottom by which the condensed water, the air and the vapour are drawn into the air pump.

SUPPLEMENTARY FEED. At one end of the condenser, a pipe of small bore, and a cock or valve, connects the water chamber with the steam space. It is used only in cases of urgency when it is necessary to supply extra feed water to the boilers

CIRCULATING PUMP. This may be a double-acting reciprocating pump driven by levers from the main engine. A centrifugal pump driven by a small steam engine is, however, preferable since the condenser may then be circulated as the engines are warmed through previous to starting, or when stationary during manœuvring operations. The circulating pump draws from the sea through the **MAIN INJECTION VALVE,** which is a screw down lift valve, and delivers through the condenser. The quantity of circulating water required depends upon the sea water temperature and the speed of the engine. It is regulated in the case of the reciprocating pump by adjusting the amount the injection valve is open; by changing the speed of rotation in the case of the centrifugal pump. The discharge cir-

culating water should not be allowed the exceed 110° F. or scale may be deposited on the inside of the condenser tubes, thereby seriously reducing their efficiency as conductors of heat.

AIR PUMP. This is the pump which removes the condensed steam from the condenser, but an equally important function which it performs is to remove the air and water vapour also and so maintain the low pressure required. It is always a vertical single acting reciprocating pump, generally driven by levers from the main engine. Its stroke is about one-half that of the main engine and its capacity about $\frac{1}{20}$ that of the L.P. cylinder. An air pump having 24 inches stroke delivers only about $\frac{1}{2}$ inch depth of water over the bucket each up (delivery) stroke; for the remainder of the stroke it is delivering air and vapour.

Two types are common in the merchant service, and these are briefly described and their action explained.

COMMON AIR PUMP. This type has suction valves at the bottom of the pump chamber, generally called the **FOOT VALVES,** Valves in the bucket—the **BUCKET VALVES,** and delivery valves at the top of the pump chamber referred to as the **HEAD VALVES.** All these valves open upwards and are non-return automatic valves. The lower end of the pump is arranged below the level of the condenser so that the condensed steam flows to the suction end of the pump. The action of the pump is as follows:—Imagine the bucket at the top of its stroke and starting to descend. The space between the bucket and the head valves is filled with water and air, and as the bucket moves down the pressure in this space decreases, causing the head valves to close. The foot valves also close because the pressure below the bucket increases as the bucket descends. At some point in the down stroke the pressure on each side of the bucket becomes the same and the bucket valves open allowing air and vapour to pass above the bucket, followed by water at the end of the stroke. As the bucket ascends the pressure below the bucket decreases, causing the bucket valves to remain closed, whilst the pressure above the bucket increases. Eventually the pressure below the bucket is reduced sufficiently to allow the foot valves to open and more air and water to enter the chamber from the condenser; about the same time the pressure above the bucket is sufficient to cause the head valves to open and discharge to take place into the hotwell.

The pump bucket is usually packed with rope. The valves always have a layer of water over them—they are "water sealed" and the efficiency of the pump is high. An objection to this pump is the number of valves necessary, and the type most often fitted to modern engines is the:—**EDWARD'S AIR PUMP.** This type has only delivery or head valves. The reciprocating piston of the pump is flat on its upper surface and conically shaped below, the bottom of the pump chamber being shaped to correspond. The

pump liner has a ring of ports around its lower end extending for the whole circumference and these ports communicate with the condenser, The action of the pump is as follows :—

As the piston descends on its stroke expansion occurs between the piston and the head valves. At about $\frac{7}{8}$ of the down stroke, when the pressure above the piston is sensibly less than the pressure in the condenser, the piston uncovers the ports in the liner. Air and vapour at once enter the chamber from the condenser and this is followed immediately afterwards by water from below the piston. This water has drained from the condenser into the conical base of the pump chamber, and it is displaced therefrom by the conical bottom of the piston, guide surfaces being arranged to deflect the water through the ports. As the piston ascends it first closes the ports, then compression occurs between the piston and the head valves until the pressure is great enough to cause the head valves to open and the contents of the chamber to be discharged into the hotwell. Only very small clearances are required at each end of the stroke,

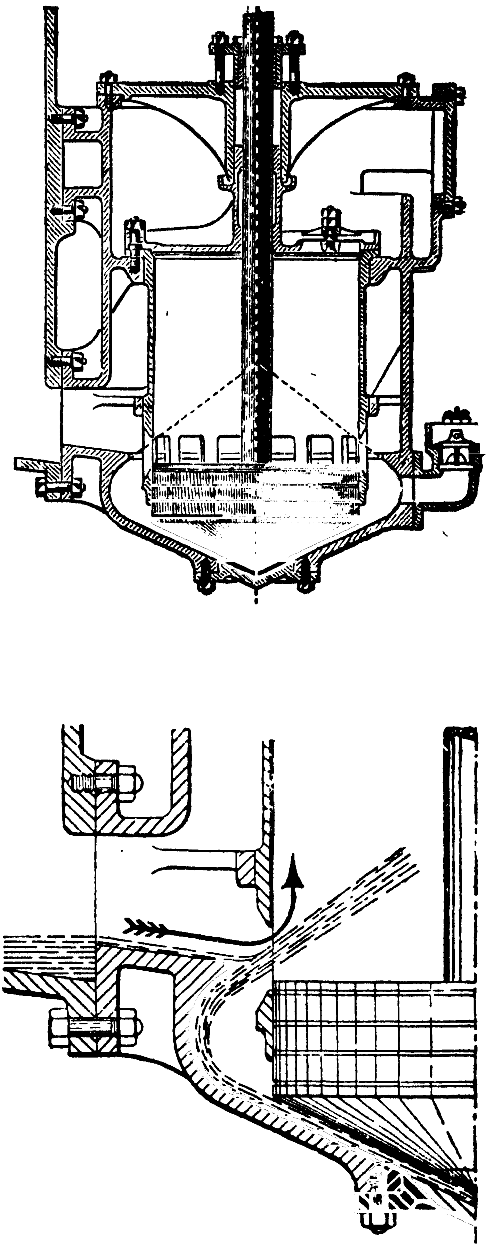


Fig. 28.

and in consequence the efficiency of this type is high, but great care must be exercised when overhauling the pump to see that the clearances are correct. Wear at any of the bearings of the pump levers or link brasses, or on the main engine bearings, all tend to make the clearances incorrect.

TAIL VALVE. This is an automatic valve arranged at the bottom of an air pump to permit water, which accumulates here when the engine is stationary, to escape to the bilges. It is kept closed by the atmospheric pressure when the pump is working, but when the engine is stopped and the pressure in the condenser and hence in the bottom of the pump becomes equal to the atmospheric pressure, it will open and free the pump of water.

FEED PUMPS. The water delivered by the air pump into the hotwell is pumped back into the boilers by the feed pumps. Two types are used in the merchant service—pumps driven by levers from the main engines and independently driven pumps.

The main engine pumps are single acting ram pumps delivering water only on the down stroke. Two separate pumps are always fitted, each being capable of delivering sufficient water to feed the boilers; but although so designed, both pumps are always in action together. Ram force pumps have certain disadvantages. They will seldom pump water at a temperature in excess of 160° F. A considerable amount of air must be admitted with the water on the suction stroke to act as an air cushion to lessen the shock of the ram when striking the water. Some of this air passes into the boilers with the water and becomes an active agent in bringing about corrosion; and further, it is difficult to maintain the glands in a satisfactory condition over a long passage. Any adjustments that are required to the suction or discharge valves, or to the glands, generally necessitate stopping the main engines.

INDEPENDENT FEED PUMPS are usually double acting vertical pumps having a steam cylinder arranged above the water cylinder, the steam piston and the water piston being on the same rod. They are often fitted in duplicate so that one pump can be kept in readiness to take the place of the pump which is on duty. Their speed is automatically controlled by a float in the feed water tank, or in the heater, which acts through a system of levers upon the steam supply valve of the pump. They are speeded up, or slowed down depending upon the quantity of water available for them to pump. They work at low speeds, and they require no air cushion for satisfactory working; also, they can pump water which has a temperature upwards of 200° F. Their steam consumption, however, is very great, because from the nature of the duty they have to perform, i.e., to pump against a constant resistance, very little use can be made of expansion in the steam cylinder. They have no other disadvantages, and all modern engines are equipped with independent feed pumps.

BILGE INJECTION. A branch pipe is fitted to the pipe line leading from the main injection valve to the main circulating pump. This branch pipe leads to a strum box placed in the 'thwartship bilge connecting the port and starboard engine room bilges, or in the open bilge below the boilers if there is no tank below the boilers. See Fig. 27.

A NON-RETURN VALVE, normally kept closed by a screwed spindle, is arranged in this branch pipe line. This is the **BILGE INJECTION VALVE.** It is only used in cases of urgency when there is a greater influx of sea water into the machinery space than can be coped with by the bilge or ballast pumps. If the bilge injection valve is opened and the main injection valve partly, or entirely closed, the main circulating pump will draw water from the bilge and deliver it overboard through the main condenser. It may be noted that the capacity of the main circulating pump is much greater than that of any other pump fitted in the engine room.

ACTION OF THE SLIDE VALVE.

THE FUNCTIONS OF THE SLIDE VALVE ARE:—To admit steam alternately to each side of the piston; to cut off the supply of steam when the desired fraction of the stroke has been performed; to allow the expanded steam to escape to the receiver of the next engine, or to the condenser; and to retain a part of the exhaust steam in the cylinder, that it may act as a cushion in bringing the piston to rest at the end of the stroke. A valve which carries out those duties while sliding over the ports which lead to the ends of the cylinder is a slide valve, whatever its form may be.

PISTON VALVE. The piston valve is a cylindrical form of the slide valve. The ordinary slide valve has its back surface exposed to the pressure of the steam which presses the valve on to its face with great force. Considerable power is needed to work a slide valve using high pressure steam, and the wear of the gear driving the valve may be great. The piston valve, being cylindrical, is not subject to a steam load pressing it to its working surfaces. The piston valve is generally used for H.P. engines, and slide valves are mostly used for I.P. and L.P. engines. The action of both types of valve is identical. The slide valve is given a reciprocating motion over the face on which it travels, and this motion is imparted to it by the eccentric sheave.

THE ECCENTRIC SHEAVE is a modified form of crank suitable only for converting a rotary into a reciprocating motion. It consists of a disc of cast iron mounted upon the shaft in such a manner that the centre of the disc is eccentric to the centre of the shaft. The amount of this eccentricity is equivalent to the length of a small crank, and is called the "throw" of the eccentric. The **TRAVEL OF THE VALVE** is the distance it moves between the

top and bottom of its stroke, and this travel is twice the throw of the eccentric. When an engine is required to turn in one direction only, one eccentric sheave is needed; but when an engine is required to reverse its direction of motion, two eccentric sheaves are needed. One eccentric is keyed on to the shaft in such a position that it

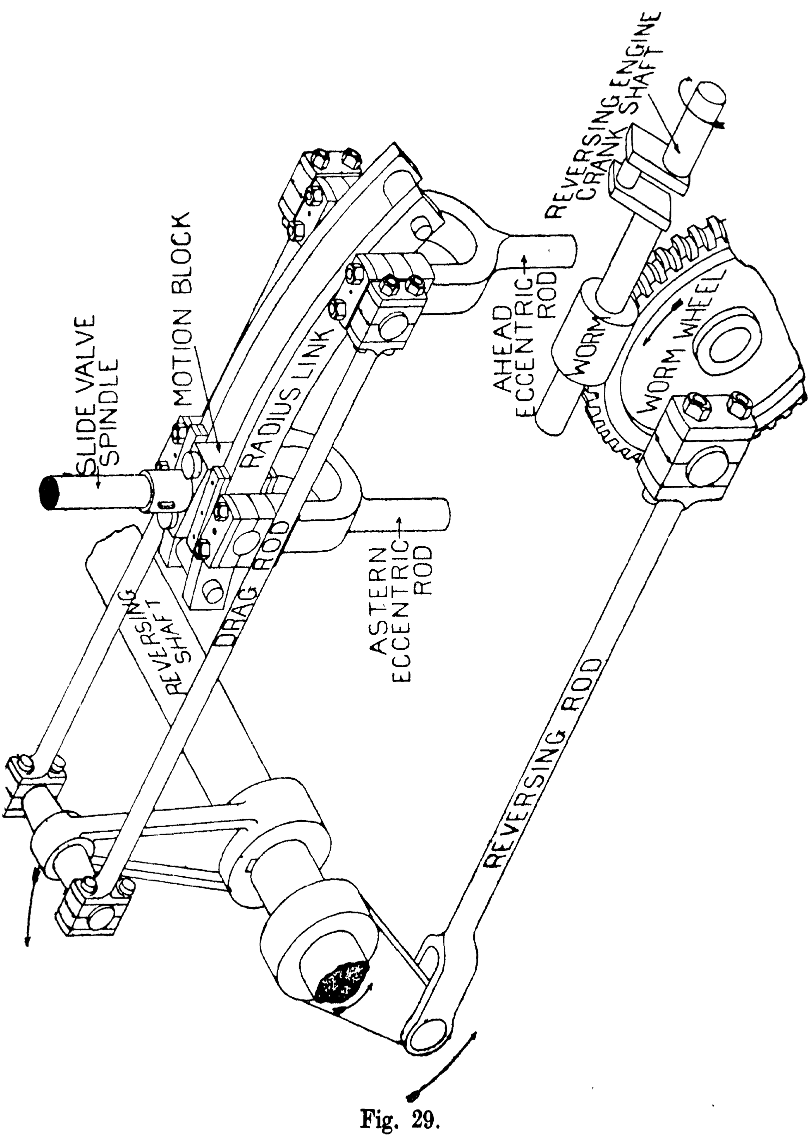


Fig. 29.

controls the valve when the engine is running ahead; the other eccentric is "set" so as to control the valve when the engine is running astern.

THE ECCENTRIC STRAP encircles the eccentric sheave, and transmits the reciprocating motion to the eccentric rod. The eccentric strap is in two halves, generally made of cast steel lined with brass or white metal on the working surface; the two parts of the strap being bolted together. The strap is connected to the eccentric rod by studs and nuts.

ECCENTRIC RODS are mild steel forgings having a flat foot at their lower ends for connecting them to the straps, and a double eye at their upper ends, by which they are attached by brass bearings to pins forged on the radius links.

RADIUS LINKS. A steam engine required to run only in one direction, say for driving a dynamo or centrifugal pump, would have its eccentric rod double eye connected by a pin to an eye formed at the end of the slide valve spindle, and only one eccentric would be required. But for main engines, which must be reversible, arrangement must be made by which, in effect, the slide valve spindle may be connected to either the ahead of the astern eccentric rod at will. The radius links are two curved bars of mild steel arranged parallel about 4 inches apart. Bearing pins at their ends allow connection to be made to the eccentric rod.

THE LINK BLOCK or motion block is the bearing attached to the lower end of the slide valve spindle. This bearing has slippers on either side arranged so that the radius links may freely slide between the slippers, and in this manner either one, or the other of the eccentric rods may be brought into line with the valve spindle. The arrangement, and also the method of moving the eccentric rod into line with the valve spindle to give the required direction of rotation to the engine, is shown in Fig. 29.

DRAG RODS. Two mild steel rods, having bearings at each end, are connected at one of their ends to the pins on the radius links. the other ends are connected to pins or an arm called the reversing arm.

REVERSING ARM. One is required for each engine. They are usually steel castings keyed to a heavy shaft, which is supported in bearings on the engine frame-work. This shaft extends the whole length of the engine, and it is called the reversing shaft.

THE REVERSING SHAFT. This shaft can be rotated through an angle of about 90° by the reversing engine. When at one end of its angular movement, the reversing arm has moved the radius link so as to bring say the ahead eccentric rod into line with the slide valve spindle, and the gear is in " full ahead position." When

the reversing arm is moved into its other extreme position, the astern eccentric rod is in line with the slide valve spindle, and the gear is in " full astern " position.

Fig. 29 shows the relative position of the parts of the reversing mechanism which have been described. It also shows one method by which the oscillating motion is imparted to the reversing shaft by the reversing engine.

If the gear is brought to rest so that the valve spindle is mid-way betwen the two eccentric rods, the gear is said to be " middled " and the engine cannot run in either direction even though the stop valve is opened. An engine may be stopped immediately by running the gear into " middle position."

When running in full gear, the eccentric rod is in line with the slide valve spindle, and the slide valve moves through its maximum travel.

LINKING UP. When the radius link is moved so that the valve spindle and motion block is at some position between the eccentric rod and the middle of the link, the gear is said to be **LINKED UP,** and the travel of the valve is reduced. Linking up the valve gear of an engine has the effect of reducing the revolutions and the horse power developed, and of effecting a saving in the fuel consumption. If a voyage has to be made at reduced speed the engine should be linked up, but full boiler pressure should be maintained. If the speed cannot conveniently be reduced sufficiently by linking up, then the stop valve may be partly closed also. When manœuvring the engine, the desired speed is always obtained by adjusting the opening of the stop valve—the slide valve gear being in the full ahead, or full astern position.

EXPANSION BLOCK. In the majority of marine engines an arrangement is fitted to each reversing arm of the slide valve gear by which each engine, H.P., I.P. or L.P., may be " linked up " a small amount independently of the others. This enables the engineer to " balance the powers," that is to cause each engine to develop approximately equal power.

ACTION OF THE SLIDE VALVE. A complete investigation of a slide valve is beyond the scope of this book, but sufficient information may be given to enable its action to be understood.

The simplest form of a slide valve is shown in Fig. 30. Its length is exactly equal to the distance between the edges of the cylinder ports, i.e., the valve has no lap. The centre line of the eccentric which controls the action of this valve must be at 90° to the centre line of the crank. The eccentric rod must be of such a length, that when the crank is on either dead centre and the eccentric sheave 90° from its end positions, the slide valve will be in its mid position, entirely covering the steam ports.

Imagine the crank is on the top centre and the piston about to start the down stroke, as shown in Fig. 30. (*a*) Immediately the piston moves, the valve also moves, the top cylinder port is opened to steam and the bottom to exhaust. When the valve reached its lowest position, which must be when the eccentric has moved through 90°, the crank has also moved through 90° and the piston has moved through approximately half the stroke. The position of valve and piston, also of eccentric and crank are as shown in Fig. 30 (*b*). Notice that the top port is full open to steam and the

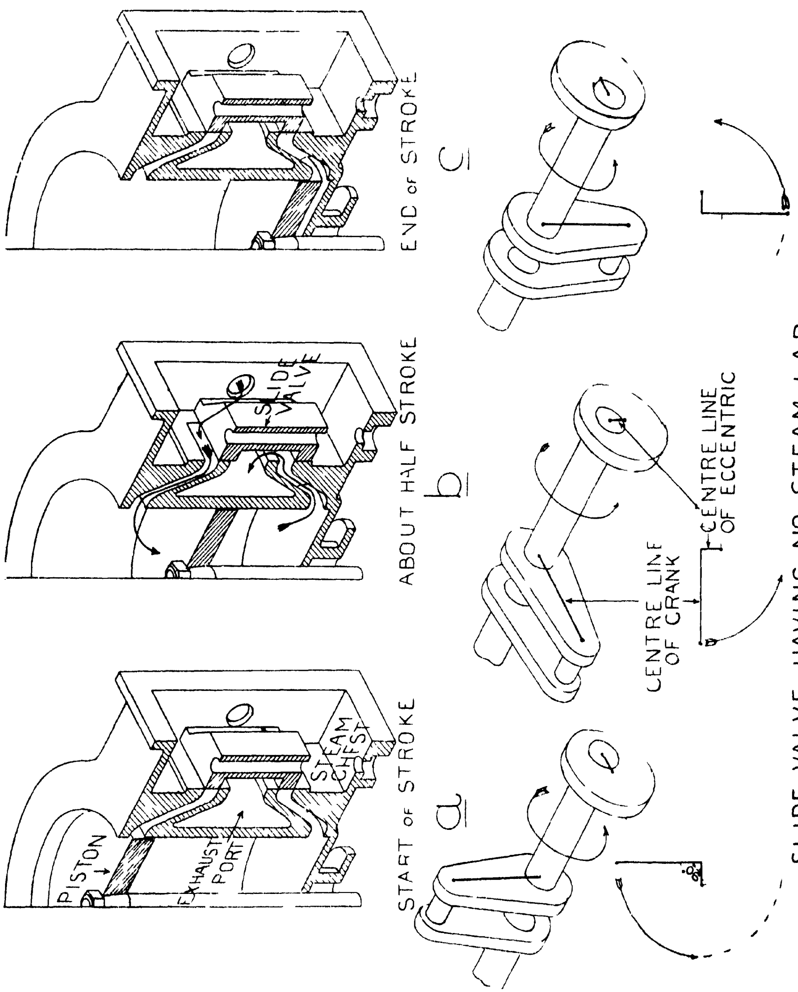


Fig. 30.

bottom port full open to exhaust. A further movement of 90° of the engine brings the piston to the end of its stroke and the valve back in its middle position, as seen in Fig. 30 (*c*). On the next stroke the reverse action occurs. Evidently, then, this form of slide valve must admit steam whilst the eccentric moves through 180° and the crank through 180°, and also the valve is open to exhaust for the same angular movement. Steam is admited for the entire stroke and it is not used expansively ; exhaust is open for the full stroke and there is no cushioning effect. This would not be suitable for main engines, but in certain auxiliary engines, such as steam steering engines and steam windlasses, this form of valve is fitted.

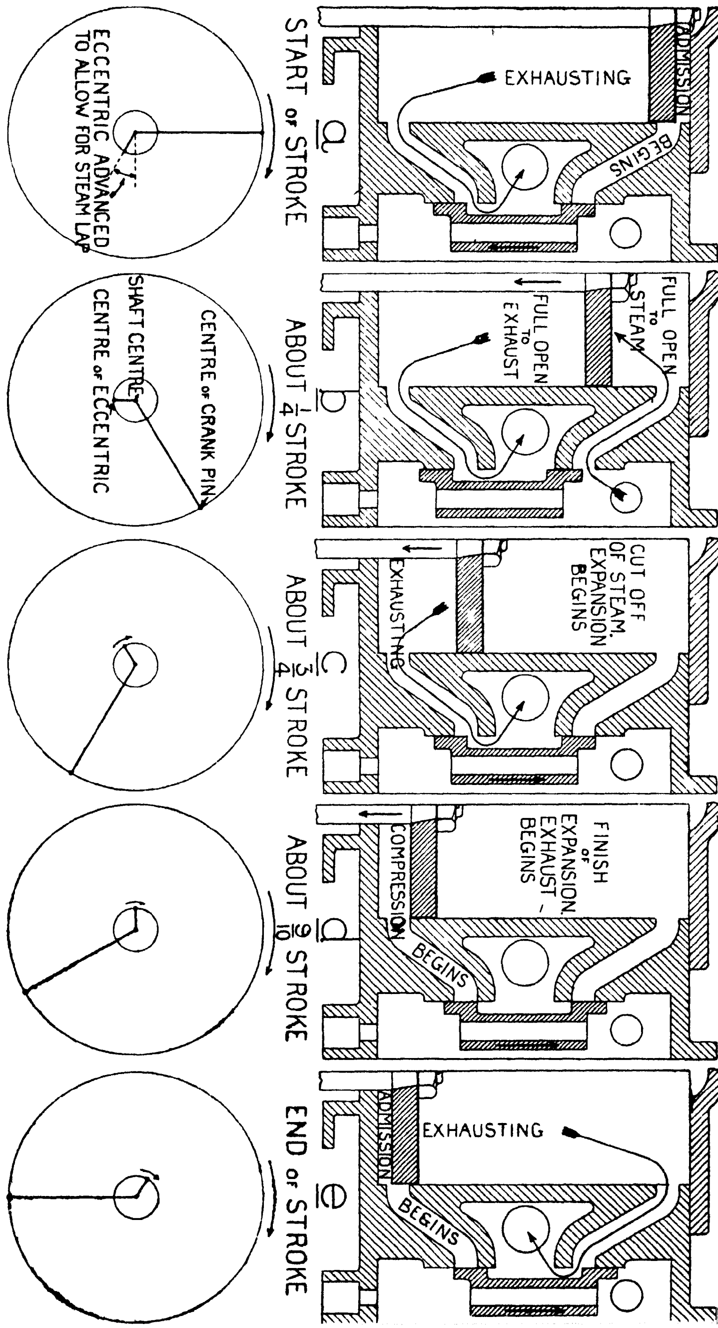
STEAM LAP. To enable the steam to be cut off before the piston has completed its stroke, the valve is made longer than the distance between the edges of the cylinder ports, and the amount by which the valve overlaps the ports when it is in the middle of its travel is called the steam lap. Overlap may be given to the exhaust edges of the valve also, in order to increase the cushioning effect, but this is not always done, and it will suffice to assume that there is no overlap on these edges.

Having increased the length of the slide valve, i.e., having given it steam lap, it is apparent that if the eccentric is retained in its former position, the valve will cover the ports when the engine is about to start its stroke. The piston would have to move some distance along its stroke before any steam would be admitted. Evidently this would not be suitable, and the eccentric must be **ADVANCED.** The eccentric is moved round the shaft, in the direction in which the engine rotates, until the port is again just about to open to steam when the crank is on the centre, and it is secured in this position.

The eccentric centre line has been advanced, the angle between the eccentric centre line and the crank centre line is now greater than 90°. The position of the piston and valve, and of the crank centre line and eccentric centre line when the down stroke is about to start is shown in Fig. 31 (*a*). Notice that the bottom port is open to exhaust, and the natural inference is that it must have opened to exhaust before the piston reached the top of its stroke.

Fig. 31 (*b*) shows the eccentric and valve at their lowest positions, and the position of the crank and piston. The eccentric and the crank have moved through an angle less than 90°.

Further movement of the engine causes the valve to move up until the positions shown in Fig. 31 (*c*) are attained, when cut off of the steam occurs. The angle through which the eccentric has moved whilst steam was being admitted has been 180° minus twice the angle through which the eccentric was advanced to allow for the steam lap put on the valve. And this is likewise the angle through which the crank has moved. It is apparent that the greater the amount of steam lap given, the further must the eccentric be advanced, and the sooner will cut off occur.



SLIDE VALVE HAVING STEAM LAP BUT NO LEAD

Fig. 31.

The piston is now being driven by the expansive properties of the steam in the cylinder until the positions shown in Fig. 31 (*d*) are reached. The top cylinder port is just about to be opened to exhaust to bring about " release." The bottom port is just closing to exhaust and " compression " begins below the piston.

When the piston reaches the end of the stroke, the positions are as shown in Fig. 31 (*e*). On the up stroke of the piston the cycle of events occur in the same order as on the down stroke.

LEAD. In order to simplify the foregoing explanation it was assumed that the eccentric was advanced sufficiently to make the valve just about to open to steam when the crank was on the centre. It is desirable, however, that the port shall be open to steam a small amount when the engine is in this position. Lead is the amount the steam port is open when the engine is on the top or bottom centres. It is obtained by advancing the eccentric through a further small angle beyond that to allow for the steam lap, and the effect of doing this is the cause admission of the steam, cut off of the steam, release and compression all to occur at slightly earlier points in the stroke. The main reason for giving a valve " lead " is to cause admission to occur before the piston reaches the end of the stroke. Admitting high pressure steam in this manner assists in bringing the reciprocating parts of the engine to rest at the end of the stroke, and it also ensures a supply of steam at the beginning of the next stroke. The lead of a valve varies from about $\frac{1}{8}$ inch for H.P. valves to $\frac{3}{4}$ inch for L.P. valves.

High speed engines require more lead than slow speed engines.

STEAM PIPES. Steel and copper are the materials mostly used for making steam pipes.

Steel is stronger than copper, it is ductile, and steel pipes are readily bent into any desired form.

Copper suffers loss of strength when exposed to high temperatures, it loses ductility and must be periodically annealed.

Main steam pipes should be made of solid drawn steel. For sizes up to 6 inches diameter, the flanges are screwed on to the pipe ; for larger diameters the flanges are secured by riveting.

Copper pipes were formerly used for main steam pipes. The higher pressures and temperatures used to-day demand steam pipes which do not suffer much loss of strength at superheat temperatures. Therefore steel pipes should be used for superheated steam, copper pipes are not allowed.

For small diameters, where superheating is not used, the copper pipe is convenient, as it is easily bent into any desired form. The flanges are brazed on to copper pipes. For deck steam and exhaust pipes, which are exposed to the corrosive action of sea water, copper is mostly used. Feed water pipes and the bilge pipes in the engine room are generally of copper, as are the main injection pipe and the main discharge pipe.

ALLOWANCE FOR EXPANSION. On account of the expansion of steam pipes when heated, some arrangement is needed to relieve the compressive stresses. Large bends in the pipes form the most satisfactory method. Another arrangement is the **EXPANSION JOINT**; this consists of a stuffing box and gland fitted into the pipe line. The expansion joint may be bolted on to some rigid part, such as a boiler stop valve, or an engine stop valve, and the pipe is free to have end movement in the stuffing box as it expands or contracts due to change in temperature.

STEAM PACKING. Piston rods and slide valve spindle in modern high pressure engines are kept steam tight by means of metallic packing. Such packing consists of a series of rings, made of bronze or of cast iron, cut into segments, accurately fitted together. The segments are kept up to the rod by springs and by the steam pressure acting outside them.

ASBESTOS is of mineral origin. It is spun and woven into cord and sheets. It is not affected by high temperatures, and when woven with thin brass wire it may be made into a packing which wears slowly. Asbestos cloth, wire woven, is wrapped round a central core of rubber to make round or square section packing for rods of all sizes. Packing made of any sort of woven fibre, however, wears and grooves the rods, which are then difficult to keep steam tight. Generally the main engine glands are packed with metallic packing, and the smaller glands on auxiliary engines and boiler mountings are packed with asbestos packing.

There are semi-metallic packings, in which small white metal segments are woven into the asbestos to form a good wearing surface, but none of these are suitable for superheated steam.

LUBRICATING OILS. The principle of lubrication is to interpose a film of oil between two rubbing surfaces. By this means, the surfaces are kept slightly apart, and wear or abrasion due to metallic contact is reduced. Lubricating oils are viscous fluids, that is, the globules resist being separated, and these oils have only small mobility. For light, fast running machinery, "thin" oils of small viscosity are needed, and sperm oil has been much used for such purpose. For heavier duty, the oil must be viscous enough to resist being squeezed out from between the surfaces, and further it should not contain free acid, as this corrodes and destroys the smooth surfaces of steel parts. Formerly, castor oil was used for guides and main bearings, etc., of steam engines. Now, mineral oils are almost exclusively used.

Vegetable oils have gumming properties, and therefore are not desirable as lubricants; animals oil, such as tallow, have free acids present, and should not be used. Mineral oils have no free acid present, and these oils, of the correct degree of viscosity for the purpose required, are used in marine practice. Oils lose viscosity

when heated. Hence a heavy " thick " mineral oil is needed for cylinder lubrication, and the loss of viscosity must not be too great at the working temperature of the cylinder.

Vaseline, a solid form of mineral oil, is useful for tunnel bearings, and for running tackle such as the pulleys in lifting gear.

Ordinary " engine oil " is a mineral oil of medium viscosity, and is used for the bearings of main and auxiliary engines. Cylinder oil is a dark coloured " thick " oil of great viscosity, purely mineral in origin.

WARMING UP THE ENGINES. The first operation, previous to putting the engines to work, is to warm them through, that is to raise the temperature of the cylinders and steam chests to about their normal working temperature. This is done by passing a gentle current of steam through the engines by slightly opening the engine stop valve and the starting or manœuvring valves. The process of " warming up " takes from 1 to 2 hours.

Certain precautions must be observed before doing so. See that the turning engine is out of gear, and that the engines are clear of all tools and lifting tackle that has been in use during overhauling, particular attention being given to the crank pits and the pumps. See that the propeller is unobstructed by craft, and not liable to be fouled by ropes.

Open the auxiliary steam stop valves on the boiler. This gives steam to the auxiliary machinery in the engine room.

CIRCULATE THE CONDENSER. Open the main injection valve, and the main discharge valve, then pump water through the condenser by starting up the circulating pump if this is of the centrifugal type ; or the ballast pump, if the circulating pump is driven by the main engines. This is necessary, as the " warming up " steam after passing through the cylinders, must pass into the condenser.

OPEN THE MAIN STOP VALVES. Open the boiler stop valves very carefully and slowly in the manner already described. The master valve admitting steam to the reversing engine and the starting or " impulse " valves is now opened.

OPEN ALL CYLINDER DRAIN COCKS, this drains the cylinders of any water present, and will allow any water present to be drained away.

OPEN THE ENGINE STOP VALVE a small amount, this gives steam to the H.P. steam chest, then open the starting valves and admit a small amount of steam to the I.P. and L.P. engines. Sufficient

steam must not be given to cause the engines to move, although slight movement may occur as the cylinders become hot.

MANŒUVRING OR STARTING VALVES. In a compound engine, where steam is admitted first to the H.P. cylinder, and it then flows through the following cylinders in succession, it is evident that if the H.P. engine stops upon the top or bottom dead centre, in which positions it cannot exert any turning effort on the crank shaft, that it will be difficult, if not impossible, to start the engine. An arrangement of valves, called the starting valves, operated by hand from the starting platform, is provided by which high pressure steam, in reasonable quantities, may be admitted direct to the I.P. or the L.P. engines. The arrangement may consist of two valves of small dimensions (about 2½ inches diameter), in a chest, to which boiler pressure steam may be admitted. One valve controls the admission of steam to the I.P. steam chest, the other is for the L.P. steam chest. If the engine has stopped with the H.P. engine on the dead centre, steam may therefore be admitted to the steam chest of either the I.P. or L.P. engines, whichever is in the more convenient position for exerting a turning effort on the crank shaft in the desired direction of rotation.

Sometimes the manœuvring valves are small slide valves, operated by hand levers and arranged to admit boiler pressure steam to either the top or bottom of the I.P. or L.P. cylinders. This is the more effective arrangement. Starting valves are convenient means of admitting heating steam during the process of warming through.

The reversing engine may now be used occasionally to move the radius link into the ahead and astern positions, this gives steam through the ports into the cylinders, and assists in gently warming up all the parts.

Continue " warming through " until the L.P. and I.P. cylinder top and bottom covers are hot to the touch of the hand ; and be certain that the whole of the cylinders are about at their working temperatures. Ascertain again that the propeller is clear. Open the engine stop valve further and give the engines a few turns ahead and astern. The engines are now ready to be manœuvred in accordance with the orders from the bridge. It is usual to delay slacking back the stern gland and oiling the engines until just before the order " stand by " is received.

FEED CHECK VALVES. Should the feed pumps be driven by the main engines, the main check valves should be opened before giving the engines a turn, as there may be water in the feed pipes, but it is not usual to open the feed pump suction cocks until the order " stand by " is given. If independent feed pumps are fitted, then they will be used to pump water from the condenser due to the

condensing of the "warming up steam," during the warming up process; the main check valves, and the suction valve from the condenser to the feed pump, being first opened.

MANŒUVRING THE ENGINES. All orders received on the engine room telegraph are at once answered by a junior engineer, and their nature and time of receipt entered by him in the engine room log book, the engines being worked in accordance with these orders. If the operating levers are conveniently placed, as they should be, one engineer will have no difficulty in handling a set of engines of the largest size, but this is largely a matter of experience. All orders are carried out with the utmost dispatch. The speed of the engines may be most conveniently controlled by the throttle valve, the engine stop valve being used to stop the engines. Steam should be shut off from the engines before running the gear from ahead or astern, or vice versa, or the valve gear and reversing mechanism may be unduly strained, but the urgency of the order dictates the method of procedure. For instance, if the engines have been running "full ahead" and the order is given for "full astern," the throttle valve should be closed before the gear is run over. When in full gear astern the throttle valve may be opened quickly.

THROTTLE VALVE. This is an elliptical disc of brass, pivoted on a spindle passing through its minor diameter, and placed in the engine stop valve chest between this stop valve and the H.P. steam chest. It is worked by hand from the starting platform, and when shut it completely obstructs the passage of steam to the engine. It is a balanced valve and easily and quickly operated, but very often it is not sufficiently tight to stop the engine immediately. If any automatic governing gear is fitted to the engine, it is always arranged to act on the throttle valve.

ATTENTION AT SEA. It is the duty of the engineer officer on watch to see that the machinery under his charge remains in a satisfactory condition, and this is attained by careful attention always. The regulation of the feed check valves, in order to maintain a constant and steady water level in the boilers, and the testing of the water gauges at intervals, are important duties which have already been explained.

The numerous bearings of the engines must be oiled at regular intervals of time, and in very many vessels of the Merchant Marine this is a part of the duty of the engineer on watch. All the large bearings of turbines and Diesel engines are lubricated by mechanical means, but the majority of reciprocating steam engines are hand lubricated. A small quantity of oil applied to the bearings at short intervals is better than a large quantity at long intervals, and it is therefore common practice to oil the large bearings, i.e., the top end bearings, crank pin bearings, guides, motion blocks and eccentric

straps once every half hour. Pump link bearings and the bearings of the pump levers are oiled every hour, and the smaller bearings of the eccentric rod double-eyes and drag rods every two hours. The piston rods and slide valve spindles should be swabbed with a small quantity of cylinder oil once every hour. The main bearings of the crank shaft generally have automatic syphon lubricators, but it is desirable to supplement this supply occasionally by hand.

After the engines have been working for a few hours the bearings attain a normal running temperature, and what this should be is a matter for trained observation. All the large bearings should be felt by hand at least every half hour, and the lesser bearings every hour, and any change in their temperature observed and rectified. Bearings lined with modern white metal, the surfaces being in good condition and lubricated at regular intervals, should give no trouble due to over-heating—but it must not be assumed that this will be so. A small piece of the white metal surface may break away, or foreign matter may get into the bearing and cause it to heat up. If this occurs, and is detected at once, it may be remedied by increasing the oil supply to that bearing and oiling it more often. If heating continues the engine should be stopped, if possible, and the bearing slackened back, for if it becomes so hot that a part of the white metal becomes molten and " runs " the bearing will not work satisfactory until it has been taken down and the surfaces and oil grooves " dressed up." Water service pipes are arranged so that sea water may be applied to the crank pin bearings, main bearings and eccentric straps, but these are for use in cases of urgency only and should not be used immediately a bearing shows signs of over-heating.

A small quantity of flake graphite mixed with oil, and given to a bearing which has run hot, is useful in assisting to form a surface on the white metal, which may have become scored, or roughened. The thrust shaft runs in an oil bath and it generally requires no further attention than regular inspection and the addition of a small quantity of oil to the bath about once in 24 hours.

The intermediate shaft bearings are generally lubricated by means of some form of solid lubricant, and their condition and temperature should be observed every two hours.

An engineer quickly becomes accustomed to the sound made by the engines, and he is on the alert for any change in the rhythmic beat. If this occurs, he should at once ascertain the cause, for this may be the first indication of some fault developing.

The scope of this book does not call for any further detailed description of the watch-keeper's duties. He should always be within hearing of the engine room telegraph, and he should not leave the engine room during his watch.

ADJUSTMENTS IN PORT. Any bearing that has run unsatisfactorily during the voyage should be noted. It should be taken down and examined upon arrival in port, and any " dressing up " of the bearing surface required should be done. Any bearing that is known to be worn slack should be re-adjusted. Certain glands may require re-packing, or joints re-making and these are given attention. All the principal bearings should be taken down periodically for examination and adjustment even though they are working satisfactorily. The cylinders and steam chests are opened out at intervals for examination and cleaning. but no fixed period can be stated for these inspections. Generally, it may be considered advisable that all the large bearings, the cylinders, the steam chests and the pumps should be opened up every six months.

It is essential that the setting of the slide valves shall be maintained correct, otherwise the distribution of the steam will be affected. The setting becomes incorrect owing to wear taking place at the bearings of the valve gear and the eccentric straps, in other words, the valve becomes too low. This is easily rectified by putting a liner of the necessary thickness between the foot of the eccentric rod and the top of the eccentric strap.

CHAPTER V.

AUXILIARY MACHINERY.

AUXILIARY MACHINERY. Únder the name of auxiliary machinery are classified the small power units which carry on their different functions independently of the working of the main engines; in many cases, however, the working of these small units is essential for the running of the main engines.

Pumps, dynamos, evaporators, refrigerators, feed heaters etc., and all deck machinery are generally called **AUXILIARIES.**

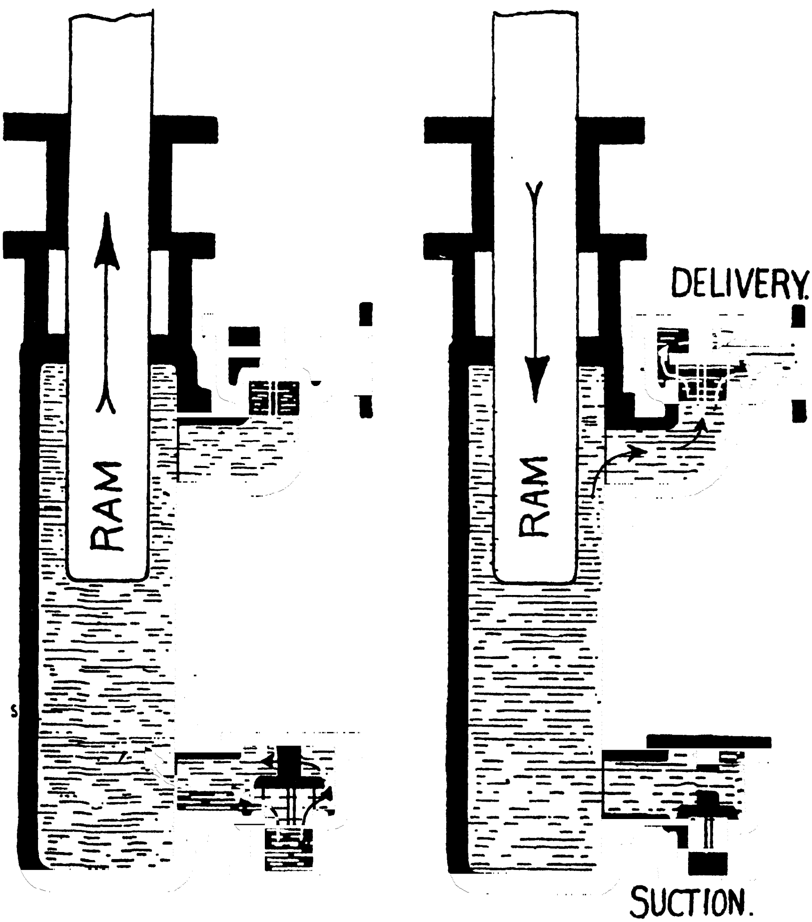


Fig. 32.

PUMPS. There are two kinds in general use—displacement pumps and centrifugal pumps.

DISPLACEMENT PUMPS are those in which the effective volume of the pump chamber is alternately increased and decreased by the movement of a ram or of a " bucket." Valves are so arranged that when the effective volume is increasing, liquid flows into the chamber from the suction pipe; and when the effective volume is decreasing, liquid is expelled or forced from the chamber into the delivery pipe.

Fig. 32 is a diagram of a **RAM PUMP.** When the ram moves up, the effective volume of the chamber (shown shaded) will increase, and the pressure in the chamber will be reduced to less than atmospheric pressure. The atmospheric pressure acting on the surface of the water outside, forces the liquid through the suction valve into the pump chamber. When the ram moves down, the effective volume of the chamber decreases, pressure is set up in the chamber which closes the suction valve, opens the delivery valve, and the liquid is expelled into the delivery pipe.

During one stroke, liquid is drawn into the chamber from the suction pipe, and during the second stroke it is expelled to the delivery pipe. A pump which delivers at each second stroke is called a **SINGLE ACTING PUMP.**

Feed pumps and bilge pumps, when fitted to the main engines are of the ram type.

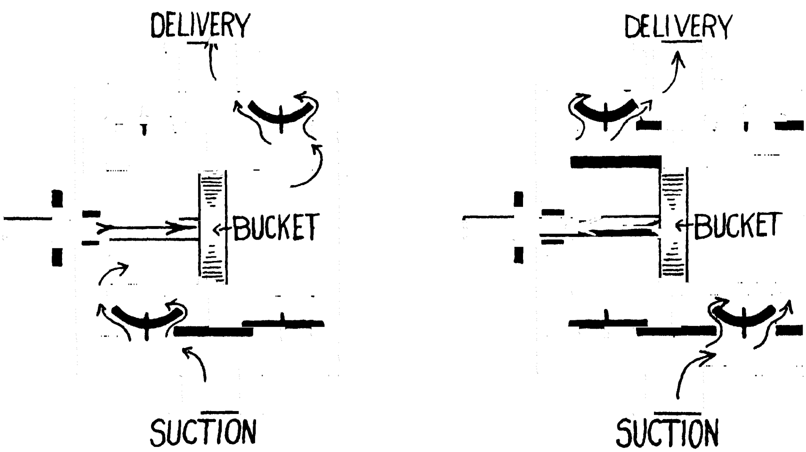


Fig. 33

Fig. 33 is a diagram of a **DOUBLE ACTING PUMP.** Each end of the pump chamber or barrel, has its own suction and delivery valves. The volume of the pump chamber is divided into two separate volumes by the bucket or piston. When the bucket is

moved along the barrel, the volume at one end is decreased, and liquid is expelled or delivered from the end ; at the same time the volume at the other end is increased, and liquid is drawn in from the suction pipe. When the direction of the bucket is reversed, these suction and delivery operations are reversed. There is, therefore, a discharge from the pump during each stroke.

CENTRIFUGAL PUMP. It is well known that when a weight is swung round in a circle at the end of a rope, there is a pull in the rope. When the rope is released the weight leaves the circular path in a straight line forming a tangent to the circle around which it has been revolving. The force which the weight exerts on the cord when it is constrained to the circular path is called **CENTRIFUGAL FORCE.**

In a centrifugal pump, liquid is admitted to the centre of a revolving paddle or **IMPELLER** and is given a circular motion. The centrifugal force due to this motion forces the liquid to the periphery of the impeller, which it leaves in a tangential direction. The pump chamber fits closely at the sides of the impeller, but has an enlargement of circular section around the outside edge. The liquid is forced into the portion which forms the discharge connection of the pump. A pipe leads into the chamber at the centre of the impeller, and this is the suction pipe. There are no valves in this pump.

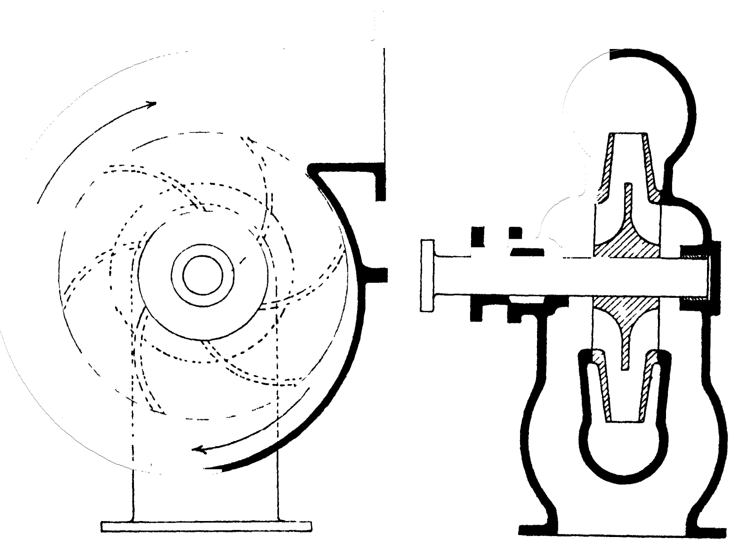


Fig. 34.

In centrifugal pumps, the outer casing is generally of cast iron. The impeller is made of cast brass, and the impeller shaft is generally of muntz metal; this shaft runs in brass bushes, and the stuffing boxes through which the shaft passes are packed with hemp packing. This pump is generally used as a circulating pump for the main condenser, and is usually driven by a small single cylinder engine. Centrifugal pumps may be designed to pump against high pressures, and some vessels have them fitted as boiler feed pumps. When so fitted, these pumps must run at high speeds, and are driven by small steam turbines or electric motors.

Generally speaking, centrifugal pumps should be placed so that the water runs by gravity into the suction pipe. As the main injection valve, from which the circulating pump takes its water, is fitted to the shell of the ship on a strake of bilge plating, the water outside is always above the pump suction pipe.

INDEPENDENT FEED PUMP. This is a double acting pump driven by a steam piston which is secured to the same rod as the pump bucket. Steam is controlled to the piston by a special form of valve. The motion is purely reciprocating, there is no rotary motion of any kind; pumps of this type are designed to work at slow piston speeds, they must be arranged to stop and to start again automatically without any supervision. Two such pumps are generally fitted to feed the main boilers, one being capable of dealing with the whole of the feed water. If a donkey boiler is fitted a smaller independent feed pump may be installed to feed it. The feed pump may have other duties than feeding the boilers, in which case it is called the **GENERAL SERVICE PUMP.** It may be used to pump sea water to the deck, or to circulate the auxiliary condenser in port, or to pump fresh water from the tanks to the deck. The feed pump must not have any suction connection to the bilges, as this would lead to contamination of the feed water. The "water end" of these pumps is generally cast iron having a brass liner fitted in which the bucket works. All valves, valve seats, buckets and rods are of brass. The packing rings in the bucket are of brass, or of woodite.

In pumps generally, all working parts exposed to salt or fresh water are made of brass or bronze.

THE BALLAST PUMP is generally of the same type as the feed pump, but of much larger capacity. It cannot pump against the same high pressure as the feed pump. It discharges overboard; but it may be used to pump up and fill ballast tanks and peaks. Its usual work is the pumping out of ballast tanks and bilges, and it may be used to circulate the main condenser.

A list of the pumps usually fitted is given, with the connections to their suctions and deliveries.

Name of Pump.	Connections to Suction.	Connections to Delivery.
Main Feed Pump	Hotwell or feed tank, condenser fresh water tanks, sea	Boilers.
Main Circulating Pump	Sea, bilge injection	Condenser and overboard.
Air Pump	Condenser	Hotwell or Feed tank.
Main Bilge Pump	Bilges, after well, Tanks	Overboard.
Ballast Pump ..	Tanks, sea, bilges	Tanks, overboard, main and auxiliary Condenser.
General Service Pump	Sea, tanks, boilers	Overboard, boilers, deck, sanitary tanks.

EVAPORATOR. Fresh water for the boilers or for the ship's domestic purposes may be obtained by evaporating sea water and condensing the steam. The evaporator is the apparatus used for this purpose. It consists of a vertical cast iron cylinder, in the lower part of which is arranged a series of copper coils. Sea water is pumped into the evaporator and surrounds the coils. Steam is admitted to the inside of the coils causing the sea water to boil and give off vapour. This vapour is led through a valve at the top of the evaporator either to the condenser or to a distiller. The solids which were dissolved in the sea water are left behind, and the dense water is blown out into the sea at intervals, to be replaced by new sea water. A small portion deposits on the coils as scale, and these are taken out and cleaned periodically. The essential fittings on an evaporator are :—A safety valve to limit the pressure inside to a safe value, and a pressure gauge to indicate the pressure ; a feed check valve for the sea water feed, and a water gauge to indicate the water level ; a steam valve to the coils and a drain cock leading from the coils to the hotwell or drain tank ; a blow down cock through which the dense water in the evaporator may be blown into the sea.

If the water is required as " make up " feed for the boilers, the vapour may be led to the condenser, where, mixing with the exhaust steam from the engine, it will be condensed and form part of the feed water.

Drinking water must not be condensed in a condenser which deals with the exhaust steam from an engine, nor may the vapour be generated in a vessel containing zinc. To obtain drinking water the vapour is condensed in a **DISTILLER.** This is really a small condenser. A cylindrical vessel contains small tubes through which sea water is circulated by a small pump. The vapour from the evaporator enters the vessel on the outside of the tubes. In condensing, the water falls to the bottom of the vessel, and after filtering through a bed of charcoal, it runs down into the fresh water tanks. The distiller is placed at a considerable height above the evaporator, as a precaution against the latter " priming " and lifting salt water into the vapour pipe ; also the condensed fresh water runs down by gravity into the tanks. Distilled water should be well mixed with air to make it palatable.

FEED HEATERS are used to heat the feed water before it enters the boilers. There are two distinct types, **SURFACE HEATERS** and **DIRECT CONTACT HEATERS.**

In the first type the water is heated by a series of tubes through which steam passes. The heat passes through the walls of the copper tubes to the water. If the heater is placed between the hotwell or tank and the suction of the feed pump, it is termed a low pressure heater. If it is placed between the delivery of the pump and the boiler, the pressure of the water must be at least equal to the boiler pressure, and the heater is termed a high pressure heater.

It is not practicable to heat the water in a low pressure heater to the same high temperature as in a high pressure heater. If the water is very hot before reaching the pump it will give off steam, and the pump chamber becomes filled with vapour at sufficient pressure to prevent the water entering. For this reason, surface heaters are usually placed between the delivery of the pump and the boiler. In the second type, the heating steam comes into actual contact with the water. Pumps deliver the water at a low pressure through a spring loaded valve placed in the top of the heater. In passing the valve the water is sprayed over a perforated cone shaped plate. The heating steam enters through a perforated cylinder placed around the cone. The steam and water are thus mixed together very intimately. The heated water falls to the bottom of the heater and from there is led to the main feed pump section.

This type of heater is placed at a considerable height above the pump suction, so that the water enters the pump under a pressure of about 5 to 10 lb. per square inch ; the temperature of the feed water is not great enough to cause the water to give off vapour under this pressure, and the pumps work without trouble.

In the bottom of the heater a float is arranged to operate a lever as the water rises and falls, and this lever controls a steam valve which regulates the speed of the feed pumps ; the arrangement is entirely automatic.

THE ADVANTAGES OF FEED HEATING. Straining of the boiler due to unequal temperature is reduced, and the boiler steams better because of better circulation. Much of the air absorbed in the feed may be driven out of the water, and this removes one of the causes of corrosion in boilers. A saving of fuel is possible and there is less tendency for the boiler to prime. By priming is meant that water is carried over from the boiler by the steam.

FEED WATER FILTERS. The oil used for cylinder lubrication must be filtered from the feed water. The filter may be placed either on the suction side, or on the delivery side of the feed pumps. In the first case, the water from the hotwell flows through a perforated cylinder which is filled with fibre, and in some cases, small coke. The oil in the water clings to the filtering medium, and the cleansed water flows on to the feed pump suction. When the filter is on the high pressure side of the feed pumps, the feed water is forced through a closely woven cloth. and the oil is left behind. The filtering medium, whether fibre or coke or cloth must be periodically renewed, and the filter cleaned out by boiling soda in it.

THE AUXILIARY CONDENSER is a small surface condenser used in port to condense the exhaust steam from the auxiliary engines. It is similar in design to the main condenser. There is no air pump fitted to this condenser, and the air escapes by a relief valve fitted to the highest part.

NATURAL DRAUGHT. In the natural draught system, the intensity of pressure of the air supplied to the furnaces is governed by the height of the funnel above the fire bars. The quantity of coal burned per square foot of fire grate depends upon the quantity of air supplied. There is a limit to the height of the funnel, and therefore to the pressure of the draught. In the natural draught system, the ashpits beneath the fires are open to the air in the stokehold, and the air is controlled by the main damper in the funnel and by the ashpit dampers. From 16 to 20 lb. of coal can be burned per sq. foot of grate per hour.

FORCED DRAUGHT. In this system the air is pumped into the ashpits by a large fan in the engine room. The fan is driven by a small single cylinder engine. The fan forces the air into an air duct which conducts it into an air heating chamber in the base of the uptake or funnel. Tubes passing through this chamber are heated by the flue gases on their way to the funnel. The air from the fan passes over the outside of these tubes, and becomes heated before entering the furnaces. The ashpits are permanently closed, and the hot air is conducted from the air heater by a trunk on the front of the boiler to a chamber above the furnaces. From this chamber the air is admitted by valves to the ashpits below the fire bars, and a supply may also be admitted above the fire bars. It is obvious that a much greater quantity of air can be supplied in this system than in the natural draught system, and from 20 to 40 lb. of coal can be burned per sq. foot of grate per hour, depending on the pressure of air supplied. This means that smaller boilers can be used for the same power.

Advantages of forced draught :—Smaller boilers are needed for the same power ; more boiler power can be obtained for the same space. Heated air enters the furnaces, and this heat has been reclaimed from the funnel gases ; hence less of the heat of the coal is wasted in raising the temperature of the air in the furnaces. As the draught does not depend on weather conditions, steaming is more regular, and there is greater control of power. With forced draught great care must be taken to keep the furnaces free from scale and oil, on account of the higher temperature of combustion ; and the tubes must be swept out frequently, so as not to become choked.

STEAM STEERING GEAR. A mechanism of any kind which moves a ship's rudder, must work intermittently. It must respond automatically to any demand which the person at the steering wheel deems necessary. The steam steering gear in its commonest form, consists of a two cylinder engine which drives a worm wheel by means of a worm on the crank shaft. The worm wheel is secured to a barrel round which the steering chains are wound. These chains are so arranged that as the barrel rotates, one length, say, on the port side is being hauled in, while the length on the starboard side is being paid out. These chains are attached to long rods of steel which carry the motion to the chains on the quadrant. Strong helical springs are placed on the steering rod line, so as to absorb the shocks which come on the rudder, and so relieve the rods and chains of sudden forces. In the case of very large rudders, the steering gear is arranged so that a cog wheel gears directly into a rack fastened directly on to the quadrant, and chains and rods are not necessary. The quadrant is free to rotate on the rudder head, and it transmits its motion by means of strong springs to the tiller firmly keyed on

the rudder head. The engine has two cylinders, and two cranks at 90°. As the engine may stop in any position, it must be able to start again from any position. The steam is carried therefore for the full length of the stroke, no expansion being attempted; steam economy is sacrificed to efficiency in moving the rudder almost instantaneously upon order. The engine must be easily reversible. This is done by a special valve motion. The slide valves fitted are of the piston type, and they have no lap and no lead. Steam may be admitted either to the ends or to the centre of these piston valves, by another valve called the control valve. When the piston valves have steam in the centre the engine runs in one direction; when they have steam over the ends, the engine runs in the other direction. The steering wheel on the bridge works the control valve through an arrangement called the " hunting gear."

ELECTRO HYDRAULIC STEERING GEAR. In this system hydraulic rams placed on port and starboard sides, are coupled directly to a tiller on the rudder stock or head. When one ram is moving out of its cylinder, the other is moving in. When the rudder is to be moved, a pump draws liquid from one cylinder and pumps it into the cylinder on the other side of the tiller. This forces out the ram on that side and moves the tiller over. The pump used is a rotary one, it runs in one direction only; there is an entrance and exit passage for the liquid, either of which may be suction or delivery. This means that the pump, though running always in one direction, can reverse the direction of the liquid flowing through it, upon demand. The pump is driven by an electric motor, receiving its current from the dynamo in the engine room.

TELEMOTOR. When the bridge is a considerable distance from the steering gear, as when the gear is in the poop, a direct connection by means of bevel wheels and rods from the steering wheel to the steering gear, becomes impracticable. An arrangement called a telemotor is used. It consists essentially of a hydraulic cylinder, fitted with a piston geared directly to the steering wheel on the bridge, and a similar cylinder and piston connected to the hunting gear on the steering engine. Copper pipes, about ⅜ in. diameter and of the necessary length, connect the two cylinders. When the piston in the cylinder on the bridge is moved by the helmsman, liquid is forced out of one end of the cylinder and moves the piston in its cylinder on the gear aft; this piston, by means of a rod, controls the action of the steering engine. The telemotor mechanism is used to control steam steering gears and electro hydraulic gears.

ELECTRIC STEERING GEARS. These gears have great advantages. especially in large ships. The only connections between the bridge, the dynamo in the engine room, and the steering gear are by means of electric cables. No telemotor or other mechanical

method of control is required. When the wheel on the bridge is turned, a variable electrical resistance or rheostat causes a dynamo in the engine room to generate current in a certain direction. This current passes aft to an electric motor, causing it to revolve. The motor is coupled by means of gearing to a quadrant on the rudder head, which is now turned.

As the motor revolves it alters another variable resistance in such a way as to cause the dynamo in the engine room to stop generating, and the motor stops because it is now receiving no current. When the wheel on the bridge is moved in the opposite direction, the dynamo generates in the opposite direction. The motor then revolves in the opposite direction, and the rudder turns towards the opposite side.

THE STEAM WINCH is a lifting machine. The power is provided by a two cylinder steam engine, which can be reversed by the usual link motion. The engines have cranks at 90°, the cranks taking the form of circular discs of cast iron keyed to the ends of the shaft, and into which the steel crank pins are secured. Steam at about 120 lb. per sq. inch is supplied through a reducing valve, when a main boiler is used; if a donkey boiler is fitted, it works at about 120 lb. per sq. inch. The exhaust from the cylinders is taken back to the auxiliary condenser in the engine room, to be condensed and pumped back into the boiler. There are two **SIDE FRAMES** upon a bed plate, all of cast iron. The side frames carry the engine cylinders and guides, and also have pockets which contain the bearings or " brasses " in which the shafts rotate. The three shafts are of mild steel. The engine piston rods and slide valve spindles should be **MUNTZ METAL** to resist corrosion by sea water—steel piston rods become corroded, and rapidly wear out the packing in their glands. The connecting rods, the eccentric rods and links, may be of forged steel, they may be drop forgings, or they may be malleable castings (page 6). All the bearing parts such as top end bearings, bottom end bearings, eccentric straps and the shaft bearings, are made of brass and are capable of adjustment for wear. The toothed wheels, the clutches, the barrel, the " warp ends " and the whipping drums are all of cast iron. The three shafts are:— The first motion or engine shaft, the second motion or whipping shaft, and the barrel shaft. The first and second motion shafts are about the same diameter, the barrel shaft is the largest and strongest shaft. Sometimes the barrel shaft is extended to port and starboard, the ends being carried in bearings on cast iron trestles, and warp ends fitted. This is convenient for shifting the ship in port. The whipping shaft has a wheel mounted upon it called the second motion wheel, and this gears into a small wheel called a " pinion " on the engine shaft. The pinion has about 14 teeth, and the second motion wheel about 42 teeth. Hence the second motion shaft runs at $\frac{14}{42}$ or $\frac{1}{3}$ the speed of the engine shaft. This speed is convenient for lifting light weights by the whipping drums.

Two speeds are provided for the barrel shaft. A large cog wheel called the "spur wheel" which has about 70 teeth, is mounted on the barrel shaft. The spur wheel gears with a pinion of 14 teeth on the engine shaft, and with another pinion of 14 teeth on the second motion shaft, in such a manner that only one of these pinions can operate at one time.

When the engine shaft drives the barrel shaft directly, the wheels engaged are the pinion of 14 teeth and the spur wheel of 70 teeth, and the speed of the barrel shaft is $\frac{1}{5}$ of the speed of the engine shaft. This speed is adapted for lifting weights by the barrel or the warp ends, somewhat greater than the loads lifted by the whipping shaft.

When the winch is put into "double gear" for its heaviest duty, the spur wheel on the barrel shaft is made to engage with the pinion on the second motion shaft, the second motion shaft being driven by the engine shaft. The speed of the barrel shaft is now $\frac{14}{42} \times \frac{14}{70} = \frac{1}{15}$, that is $\frac{1}{15}$th of the speed of the engine shaft. This arrangement is suitable for the heaviest lifts. The number of teeth on the wheels depends upon the designed lifting capacity of the winch. Winches of average size have cylinders from about 7 inches diameter and 10 inches stroke, to 8 inches diameter and 12 inches stroke. The clutches which put the pinions in and out of gear rotate with the shafts and slide along the shafts on keys or "feathers." In modern designs, the shafts are forged square in section for the length on which the clutches slide, the hole in the clutches being of square section to fit.

CARE OF WINCHES. All the engine parts should be well lubricated when shifting ship or working on cargo. Engine oil should not be used on the piston rods and slide spindles, as this may find its way into the feed water from the auxiliary condenser; cylinder oil should be used, and only occasionally for this purpose. Before starting the winch, the cylinders should be drained of all water by opening the drain cocks, and some time should be allowed for them to get hot. After work is finished the stop valve should be tightly shut and the drain cocks opened.

After leaving port, piston rods, slide spindles and clutches should be well lubricated with heavy oil, such as cylinder oil, and the clutches should be frequently moved and oiled; if this is neglected they sometimes become immovable and fixed to the shafts by rust. Any adjustments to the various bearings should be carried out when necessary.

In winter time, when the temperature may be below freezing point, it is necessary to guard against water being left in the deck steam pipes, as this water may freeze and, by its expansion, burst the pipes. The following method is adopted. Start up all the winches

and the windlass engines, letting them run slowly. Open all the cylinder drain cocks so that steam blows from all of them, and open all the drain cocks on the deck steam pipes.

Now shut down the valve on the boiler which supplies steam to the deck. The winches will soon stop, having used practically all the steam in the pipes. The drain cocks on the pipes should be left open, as should the cylinder drain cocks. After a while, when the pipes and cylinders are drained, the winch stop valve may be closed.

When starting up again, the boiler stop valve should be opened carefully and slowly. When all the drain cocks on the deck steam pipes are seen to be blowing steam, they may be closed, and the winches warmed before starting.

LIFTING CAPACITY. Messrs. Clarke, Chapman, Ltd., of Gateshead, give the lifting capacity of their 7 inch × 10 inch winches, i.e., cylinders 7 inches diameter, 10 inches stroke, as follows:— with a steam pressure of 80 lb. per sq. inch, a load of 3½ tons can be lifted at 60 feet per minute in double purchase, and a load of 1½ tons at 150 feet per minute in single purchase ; in both of these cases the lift is done by the barrel on the main shaft. The lifts would be greater with higher steam pressures.

THE STEAM WINDLASS is driven by a two-cylinder reversing engine. Space is not available in the ordinary design for link motion, and reversing is effected by a special valve. There are three steel shafts, the engine shaft, the intermediate shaft, and the main shaft. The toothed wheels are generally steel castings. The pinion wheel, on the engine shaft has about 12 teeth, and this gears into a large wheel with about 68 teeth which is fixed on the intermediate shaft. The intermediate shaft has also two pinions with 11 teeth each, fixed to it. The main shaft is in two lengths. To each length is fixed one large wheel with 51 teeth, and one cable lifter or " gypsy," which is free to revolve on the shaft. The cable lifter is of semi-steel, bushed with gunmetal, so that it rotates easily on the main shaft when the anchor is " let go." Each cable lifter is provided with a powerful screw band brake for controlling the speed of the cable when " paying out." and for locking when needed. The pinions on the intermediate shaft gear into the wheels on the main shaft. The windlass is therefore a double purchase machine. In the older designs, each cable lifter is driven by the large wheel by means of a large friction clutch lined with brass, this clutch being operated by a single square threaded nut. In the modern design the cable lifter is driven during " heaving up " by direct engaging of projections or horns on the cable lifter with horns on the main wheels, and slipping cannot occur, a hand wheel and screw being provided for engaging the horns. The cable lifters are entirely independent. The anchors may be lifted both at once, or separately,

or one may be lifted while the other is being " let go." The ends of the intermediate shaft are provided with warping drums to assist in moving the ship in port. Hand gear is fitted to operate the windlass when steam is not available. Messrs. Clarke, Chapman, Ltd., give the following particulars of their steam windlass, of which the previous paragraph is a description.

For a vessel of about 10,000 tons, the windlass cylinders are about 10 inches diameter, and 14 inches stroke, the anchors being attached to 2½ inch cable. With a steam pressure of 100 lb. per square inch, this windlass is capable of exerting a direct pull on the cables at the cable lifters of 16½ tons at 38 feet per minute, or a pull in the warp ends of 6 tons at 155 feet per minute.

The windlass needs the same attention as the winches to keep it in working order. The piston rods, guides and shoes, valve rods, clutches, screw gear, and all running parts should be well protected from sea water by heavy grease while at sea. The cable lifters should be well oiled to run freely on the main shaft before " letting go." All engine parts should be cleaned and oiled, the engine cylinders warmed up, and the engine started slowly before engaging the cable lifters to " heave up."

MECHANICAL REFRIGERATION.

The atmospheric microbes which are the chief causes of fermentation and putrefaction in organic matter, are mostly of vegetable origin. These microbes are rendered inactive at low temperatures, some may be destroyed ; hence to keep foodstuffs from putrefying, they must be stored in chambers cooled to the correct temperature.

There are two methods of refrigeration in use aboard ship—the **COLD AIR SYSTEM** and the **VAPOUR COMPRESSION SYSTEM.**

THE COLD AIR SYSTEM. The student should read carefully through Chapter III. to gain some knowledge of the principles involved in the transformation of work into heat, and of heat into work ; it must be remembered that **HEAT AND WORK ARE MUTUALLY INTERCHANGEABLE.**

Imagine a quantity of air at atmospheric temperature and pressure.

If we could make, by some means, this air do work, it would give up heat and become colder. But a necessary condition for the air to be able to change some of its heat into work, is that its pressure must fall during the operation. It would be impossible to maintain in the holds a condition of pressure less than atmospheric, hence the condition by which the air can fall in pressure and in temperature while doing work, must be artificially produced.

We would require to maintain air at some pressure above atmospheric pressure and at about ordinary atmospheric temperature; we must be able to let this air do work by expansion until its pressure is reduced to the pressure in the hold. At the end of the expansion, because of the heat given up by the air in doing work, the air is left exceedingly cold. We proceed to describe, briefly, the arrangement by which the pressure difference, necessary for expansion and cooling of the air, is maintained.

THE AIR COMPRESSOR is the pump which compresses the air drawn from the holds to a pressure of 50 lb. per sq. inch above the atmospheric pressure. Now the work done upon the air in compressing it, considerably increases its temperature; and if the air is allowed to expand from its high pressure and temperature by giving up the work we have put into it, then it would come back to its first pressure and temperature, and no cooling effect would be obtained. But when the air has been compressed to 50 lb. per sq. inch (its temperature is then about 300° F.), it is passed into a vessel like a surface condenser called the **COOLER,** and cooled by passing through tubes round which sea water is circulated. The arrangement is such that the air is cooled down to a few degrees above the temperature of the sea water, but its pressure of 50 lb. per sq. inch is not reduced. The air is now at about sea water temperature, and can be made to do work in the expansion cylinder, by expanding and falling in pressure from 50 lb. per sq. inch above the atmospheric pressure to the pressure in the holds (atmospheric).

THE DRYER. The air, compressed and cooled, may contain moisture in the form of vapour; this moisture, if not removed, may be deposited and turned into snow or ice in the expansion cylinder, and damage may be done. The dryer is another arrangement like a surface condenser. The air after leaving the cooler at say 80° F. is passed through the tubes in the dryer. The cold air on its way from the holds to the compressor at about 20° F. passes over the surface of the dryer tubes. Any moisture in the air inside the tubes is condensed, and may be drained off as water. The air to be expanded is now dry and has been cooled from about 80° F. to about 45° F.

THE AIR EXPANDER is the cylinder in which the air now does work by moving a piston. The compressed air, now dried, is admitted to this cylinder by a slide valve which cuts off the supply at about $\frac{1}{3}$ stroke. Expansion of the air takes place with loss of heat. Finally the expanded air passes from the exhaust of the expander into the snow box through which it passes to the holds at about minus 90° F.

THE SNOW BOX is an arrangement of baffles in which any remaining moisture in the form of snow is deposited, and this snow must be cleared out at intervals.

Fig. 35 is a diagrammatic sketch of the arrangement.

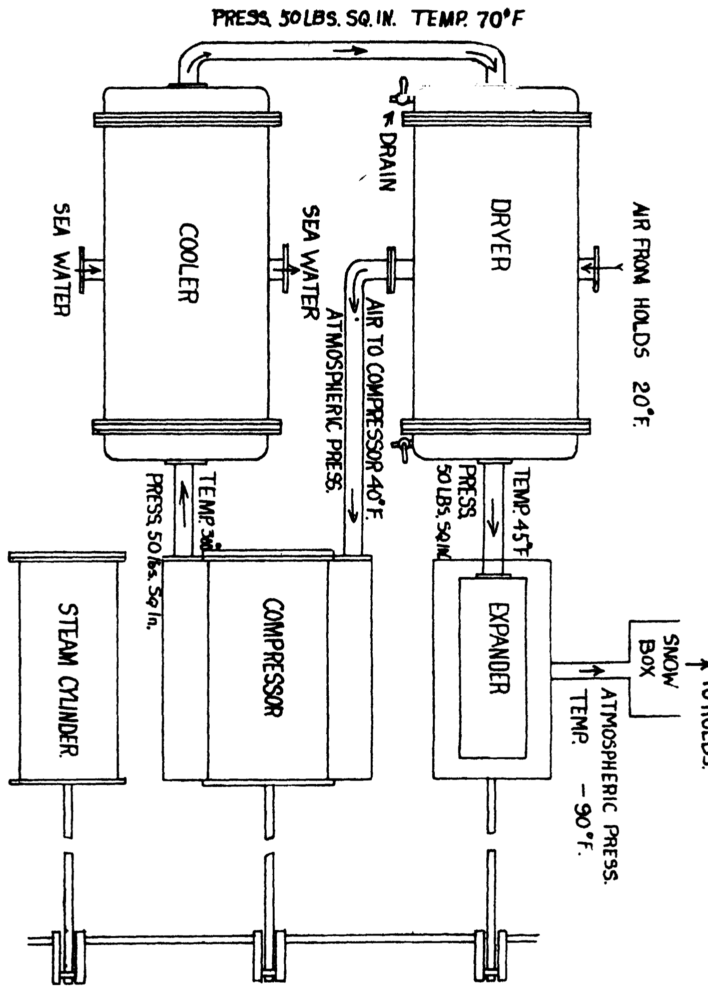


Fig. 35.

The essential parts of a cold air refrigerator are :—An **AIR COMPRESSOR, A STEAM ENGINE** to drive the compressor, **AN EXPANSION CYLINDER, A COOLER** and **A DRYER.**

In one form this machine has a crank shaft with three cranks. The steam engine acts on one crank and this drives the crank shaft. The compression is worked by the second crank. The expander is connected to, and does work on, the third crank. The air expanding in the expansion cylinder does work and helps the steam engine to turn the crank shaft. In short, some of the work used in com-

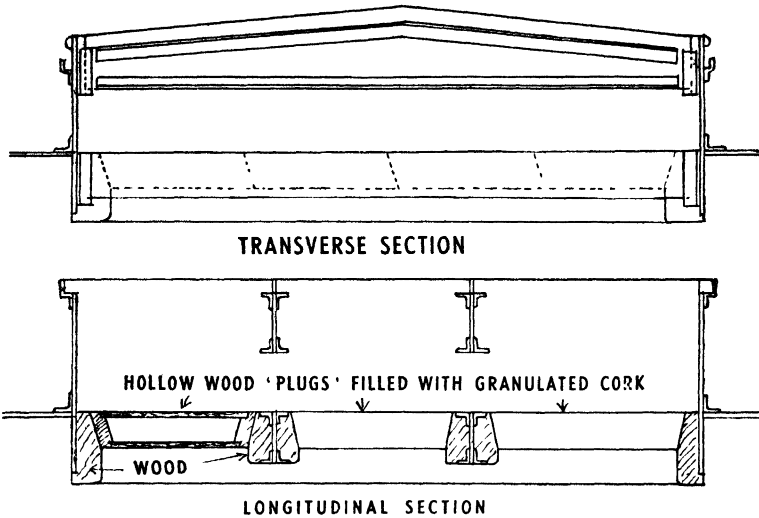


Fig. 36.

pressing the air is given back by the expansion cylinder to the crank shaft. It is not possible to regain all the work put into the air by the compressor. Some of this work is lost in friction ; the heat of compression representing much of the work put in, is taken away by the cooler. Roughly, about half the work done in compressing the air is recovered in the expander.

The cold air machine is large and heavy, and occupies a large space ; it was the first system in use aboard ship. The vapour compression system is mostly in use in modern practice. The holds must be carefully **INSULATED** to prevent heat from being conducted from the sea to the cold air.

A sketch shows the arrangement. Wood, cork shavings, and silicate of cotton are the non-conducting materials used. The wood sheathing in the holds is covered with sheet zinc for protection.

THE VAPOUR COMPRESSION SYSTEM. In this system the refrigerating medium is a volatile liquid, which when it vapourizes takes latent heat from any substance sorrounding it, producing a state of intense cold in the substance. It must be remembered that latent heat is the heat necessary to change the physical state of matter, and before a liquid can change into a vapour it must be given latent heat. For instance, if a few drops of methylated spirit be poured into the palm of the hand, the spirit soon evaporates into a vapour, the latent heat necessary for the change from the liquid into the vapourous form being taken from the hand, which is at once cooled by the loss of heat. Such a method of cooling is obviously expensive, and would require an endless supply of

the cooling agent. The following method describes how the same quantity of refrigerating agent is used over and over again, the only additions to it being due to the slight leakages which occur.

The refrigerating agents used are vapours which exhibit low temperatures at high pressures, and which can be readily changed, by giving up latent heat, into the liquid form. When in the liquid form, if the pressure is allowed to decrease, the substance evaporates into its vapour form, taking latent heat from any material surrounding it.

Thus the refrigerating medium exists alternatively in the liquid and the vapour form. In the liquid form, at a low pressure and temperature, it takes in latent heat from the substance to be cooled, and changes into a vapour. In the vapourous form it is compressed to a higher pressure and temperature, when it is condensed back into a liquid by giving up its latent heat to the sea water in the condensing system. Thus heat is taken in at a low temperature and given up at a higher temperature. Now heat cannot pass from a cold body to a hotter one by any self-acting process, hence mechanical work must be expended to carry out the operation.

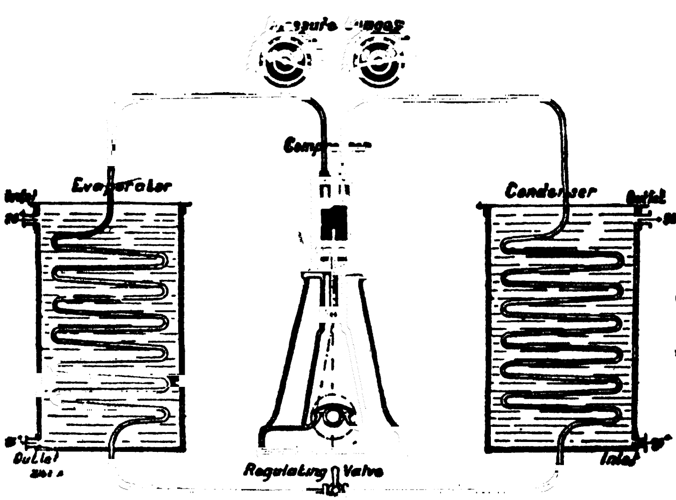


Fig. 37.

THE AMMONIA COMPRESSION SYSTEM. Anhydrous ammonia, or ammonia free from moisture exists as a vapour at atmospheric pressure. It may be compressed and cooled into the liquid form, and as such it is supplied in cylinders containing from 50 to 100 lb. weight. At a pressure of 33 lb. per square inch, ammonia will vapourize at a temperature of 5° F. or 27° F. below the freezing point of water.

The refrigerating plant consists essentially of a steam engine to drive the compressor, a compressor, a condenser, an evaporator or refrigerator and a regulating valve.

THE COMPRESSOR is a double acting pump which takes in the ammonia vapour and compresses it to a pressure of about 180 lb. per sq. inch, the temperature being about 88° F. This compressed vapour is now delivered into the condenser. **THE CONDENSER** consists of a vessel containing a coil of tube through which the ammonia flows. Sea water is pumped through the vessel and round the outside of the coil. The ammonia vapour in the coil gives up its latent heat to the sea water outside the coil, and changes into the liquid form. The liquid ammonia is taken from the coil in the condenser by a pipe to the regulating valve.

THE REGULATING VALVE may be so adjusted as to reduce the pressure of the ammonia. When the pressure is reduced, the temperature of evaporation is lower.

THE EVAPORATOR. From the regulating valve, the ammonia at a pressure of about 30 lb. per square inch, passes into the coil in the evaporator or refrigerator. As the pressure has been reduced in passing through the regulating valve, the ammonia changes back into a vapour, taking latent heat from the brine surrounding the evaporator coil. The evaporator is a vessel containing a coil through which the ammonia, changing from a liquid into a vapour, passes. The brine surrounds this coil, and it must supply the latent heat to the ammonia. The brine is thus made very cold. The brine is pumped through a system of pipes in the holds and other compartments that are required to be kept cold.

After being completely vapourised in the evaporator the ammonia is drawn into the compressor and the cycle begins again.

Heat is taken from the brine by the ammonia changing from a liquid into a vapour. As a vapour the ammonia is compressed. At the pressure of compression it is cooled and condensed back into a liquid, giving up to the sea water the latent heat it absorbed from the brine. Thus the heat taken from the holds by the brine is ultimately absorbed by the sea water in the ammonia condenser and finally discharged overboard. In the liquid form the ammonia passes from the condenser to the regulating valve where its pressure is reduced. After the pressure is reduced the liquid ammonia begins to change into a vapour. The pipe from the regulating valve takes the vapourising ammonia into the refrigerator, where it takes the latent heat to completely change into a vapour from the brine surrounding the coil.

Ammonia has some disadvantages. It has a strongly corrosive action upon copper and copper alloys, and all parts such as coils, compressor valves and pistons, etc., must be made of iron or steel; no copper or brass can be used in contact with ammonia. Should a leak occur in the system, great inconvenience and danger may be caused by the pungent offensive odour. An ammonia machine should not be placed in the same compartment as the propelling machinery, as any leakage of ammonia would make it impossible for anyone to remain in the engine reom.

BRINE is made by dissolving calcium chloride in fresh water. About 40 ozs. of calcium chloride per gallon of water is the best proportion. The freezing point at this density is — 21·5°F.

Common salt (sodium chloride) should not be used for this purpose since it is corrosive to steel. It could be used for a short period in an emergency, but should be discarded as soon as possible. Sea water has a freezing point of about 29°F. and is therefore entirely unsuitable.

The temperature of the brine leaving the evaporator depends upon the temperature required in the holds, and it may vary from 35° F. to 5° F. The quantity of brine passing to any compartment may be controlled by a valve.

THE CARBONIC ACID (CO_2) SYSTEM. The principle of working and the arrangement of the parts is the same here as in the ammonia system; the machine requiring a steam engine, a compressor, a condenser, an evaporator and a regulating valve. The difference is solely in the choice of the refrigerating agent. CO_2 is a non-poisonous gas and may be compressed and cooled into the liquid form; it is supplied in steel bottles containing from 50 to 100 lb. weight. The pressures throughout the system are much higher than in the ammonia machine, being about 1,150 lb. per sq. inch at the end of compression and about 260 lb. per sq. inch in the evaporator.

CO_2 has no action on copper and brass. No inconvenience or danger is caused by leakage. On the other hand leakages are more difficult to detect than in the case of ammonia, as CO_2 is odourless. In the CO_2 machine, on account of the higher pressures used, glands, pistons and valves are more difficult to keep gas-tight. There is little difference between the efficiency of the ammonia and CO_2 systems; they are both more efficient than the cold air system.

CHAPTER VI.

TURBINES, GENERAL DESCRIPTION, ETC.

In the reciprocating engine, the steam acts in much the same manner as a load or weight placed upon the piston; that is, the action of the steam is "static." In the steam turbine the force exerted on the blades by the steam is due to the velocity of the steam, and to the fact that the curved blades, by changing the direction of the steam, receive a force or impulse; the action of the steam in this case is said to be "dynamic."

In all types of turbines, the first operation is to give the steam a high velocity. This is done by allowing the steam to expand from a high pressure to a lower one.

The potential energy stored in the steam at the higher pressure, is changed into energy of motion or kinetic energy in the steam at the lower pressure; the heat energy given up by the steam during its fall in pressure, makes its reappearance in urging the steam along at a high velocity. Note that the original energy is still possessed by the steam, but that the form of this energy has changed. The blading of the turbine absorbs this velocity energy or kinetic energy of the steam, and takes up part of the velocity of the steam. Turbine blades are curved in such a manner, that the steam directed upon them enters without shock, though there is always some loss of energy by the friction of the steam upon the surface of the blades.

THE IMPULSE TURBINE. In the type called the "impulse turbine," the steam is allowed to **EXPAND IN NOZZLES** whereby it gains a high velocity before it enters the moving blades of the turbine. The steam does not fall in pressure while passing through the moving blades, but its velocity is greatly decreased. The action of the jet of steam impinging on the blades is said to be "an impulse."

In the simple impulse turbine, the steam is expanded from its high pressure to the pressure of the condenser in one stage; one or more nozzles are used, and there is one wheel which rotates by the action of the steam on the blades fastened to its outer circumference.

THE DE LAVAL TURBINE is of the simple impulse type. Fig. 38 shows diagrammatically the nozzles in which the steam is expanded, and the wheel to which the blades are attached. The nozzles are tapered, being larger in diameter at the low pressure end. The wheel is made solid and the shaft is bolted to the wheel by means of

flanges. A wheel rotating at very high speed is considerably weakened by having a hole drilled through it—though in some constructions this is unavoidable.

The blades are made of special bronze or of nickel steel and are fastened into slots in the rim of the wheel as shown, and caulked in.

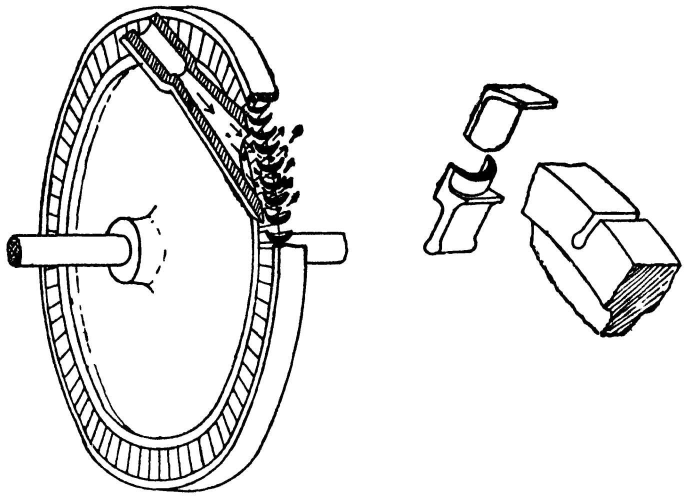


Fig. 38. Diagram De Laval Impulse Turbine.

For the best efficiency in this type, the blades should move with a speed about half the speed of the steam. Now when one set of nozzles is used, and the expansion takes place in one stage, the steam expanding through its full pressure range issues from the nozzle with a high velocity which may be as great as 4,000 feet per second ; the rim of the wheel with the blades attached will have to run at about 2,000 feet per second. This means a very high rate or rotation, in small De Laval machines as high as 30,000 revolutions per minute. Gearing must be employed to reduce this speed. De Laval turbines are mostly used for driving dynamos, and for small power purposes where high speeds can be used.

PRESSURE COMPOUNDED IMPULSE TURBINE. The steam may be expanded in stages by using a series of nozzles, instead of allowing it to fall through its full pressure range in one nozzle. This means that there must be a series of nozzles, and a series of wheels keyed to the same shaft. In the first set of nozzles, a small pressure drop occurs with an increase in the velocity of the steam ; the velocity of the steam is now much less than when complete expansion takes place from the high pressure to the condenser pressure in one nozzle. The steam is now directed on to the blades of the first wheel, the pressure of the steam does not alter in passing

through the blades, but the velocity is decreased. This constitutes one stage. Note that " a stage " here consists of one set of nozzles and one turbine wheel with its blading. The steam now enters the second set of nozzles, where its pressure is further reduced, the velocity being increased to about the same as when it issued from the first nozzles. The pressure drop per stage in the nozzles is not the same, but the number of heat units turned into velocity energy in each stage is the same. This operation is continued through all the stages until the condenser pressure is reached, when the steam is exhausted from the last wheel to the condenser. A pressure compounded turbine of this kind consists of alternate sets of nozzles, and wheels. By thus arranging a small pressure drop per stage, the steam velocity, and therefore the speed of the wheels is much less than in the single wheel type. The speed of revolution is thus much less, and for many purposes gearing need not be used

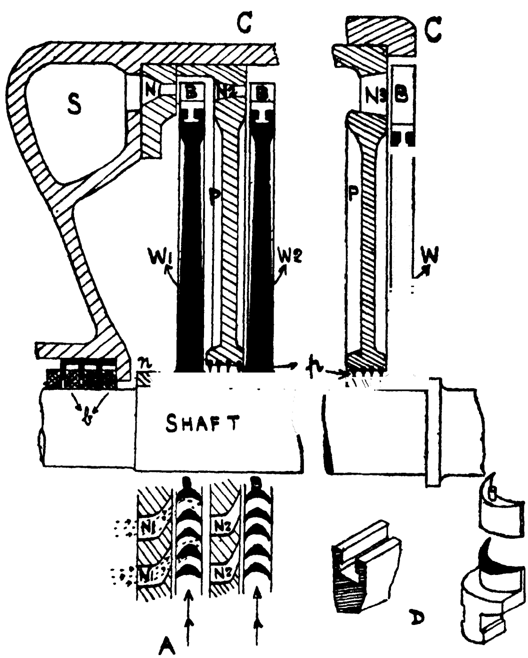


Fig. 39.

DIAGRAM OF PRESSURE COMPOUNDED IMPULSE TURBINE.

A portion of such a turbine showing 3 stages is given in Fig. 39. the stages between C and C being omitted in the sketch. Sections of the upper halves of the nozzle plates and wheels are shown.

The steam enters the nozzle box S from the boiler, and is then expanded through the nozzle N 1. The pressure is reduced in the

nozzle, the steam leaves the nozzle at a high velocity, and is directed by the nozzle on to the blades B which are firmly fixed into the rim of wheel W.1. The direction of the steam is fixed by the angle which the nozzle makes with the plane of the blades. The dotted arrows show the direction of the steam, and the arrows at A show the direction in which the blades move. In passing through the blades B, the speed of the steam is greatly reduced, since the blades absorb work from the steam. There is, however, no fall in pressure while the steam passes through the moving blades B, and consequently no leakage occurs over the ends of the blades, the steam pressure being the same in both sides. The steam now enters the nozzles in the nozzle plate or disc P which is firmly fixed to the casing C. Another drop in pressure now takes place while the steam expands through nozzle N 2, its velocity rising to about the same value as at exit from N 1. The pressure on the two sides of the nozzle plate P is not the same, and special packing to prevent leakage is shown at *p*. The steam now enters the moving blades B of wheel W 2, gives up work and therefore velocity in turning the wheel. This process is repeated throughout all the stages until the steam has been expanded down to the pressure of the condenser, when it is exhausted and condensed, then pumped back into the boiler. The nozzles N 1 and wheel W 1 with its blading B constitutes the first pressure stage. Nozzles N 2 and wheel W 2 with its blading B constitute the second stage, and so on. The expansion of the steam takes place in the nozzles only. As the pressure falls, the volume of the steam increases, and the nozzles get successively larger to allow for this. The blades are made longer on successive wheels, this makes a larger space to accommodate the larger volume of the steam as the pressure falls. The blades then are shortest at the high pressure end of the turbine and longest at the low pressure end.

THE CASING C is cylindrical and is generally made of cast iron, but it may be a steel casting. The steam chest or **NOZZLE BOX S** takes high pressure steam from the boiler through a stop valve not shown. **THE NOZZLE PLATE N 1** is of cast steel with the nozzles cast in at the correct angle, the plate being firmly fixed by bolts to the casing.

THE NOZZLE PLATES or discs P are generally of cast iron with the nozzle passages cast in. These nozzle plates are firmly secured to the casing by their outer rims; at their inner diameter, where they encircle the bosses of the wheels W, they are provided with **LABYRINTH PACKING.** This packing consists of a number of thin concentric rings of brass or bronze recessed into the discs P, a very minute clearance between their edges and the bosses of the wheels being allowed. This packing prevents leakage of steam from one side of the disc to the other.

THE WHEELS W 1, etc., are generally of forged steel, as they require to be very strong. The stresses set up in these wheels when

rotating at high speeds are great. The wheels are a tight fit on the shaft to which they are keyed, a nut is screwed on the shaft forcing them up against a solid collar.

THE BLADES B are generally of nickel steel or of a special bronze alloy. One method of fastening the blades into the wheel is shown at D. Fig. 39 the blade fitting tightly into a T slot. A shroud of thin sheet steel or brass is fitted over the ends of the blades by means of the pins, one of which is shown in D. This shroud prevents the radial spread of the steam, and strengthens the blading. The blade is broken across in the sketch to show the section.

The shaft is of mild steel, supported on two main bearings of white metal, one at each end of the casing, not shown in Fig. 39. The shaft is made steam-tight where it passes through the end of the casing, by a series of carbon rings *b*, held in place by springs, or by labyrinth packing. When used to drive a dynamo, a turbine of this kind may be used for direct driving, and speeds of rotation may be about 3,000 revs. per minute. When used for marine propulsion the speed must be reduced as described later.

EXPANSION OF STEAM IN TURBINES. It will be observed that the passage of the steam through the turbine is in one direction, there being a continuous flow from the high pressure to the low pressure end. In the reciprocating steam engine, the steam passes to exhaust through the same ports by which it enters, cooling the metal and causing the harmful condition known as "initial condensation." Since the flow of steam in the turbine is in one direction only, there is no loss due to initial condensation; this is one explanation of turbine economy. Further, the steam can be expanded to a much lower pressure in the turbine than in the reciprocating engine.

It has been shown that the object of pressure compounding is to reduce the velocity of the blades, and so to make a turbine in which the rotation speed is much less than the speed of a single impulse wheel.

There is another method for achieving this result, and it is called "velocity compounding."

VELOCITY COMPOUNDED IMPULSE TURBINE. In this type, the expansion of the steam takes place in one set of nozzles, from the boiler pressure to the pressure of the condenser. The impulse wheel, however, carries two and sometimes three rows of blades. Projecting inwards from the casing are rows of fixed blades, which occupy the spaces between the rows of blades on the moving wheel. A section of the rim of the wheel and the casing is shown in Fig. 40. The steam after expanding through nozzles N, enters the first row of moving blades M B_1. The steam after passing through M B_1 enters the row of fixed blades F B_1 with a considerably less velocity than when it issued from the nozzles. The fixed blades F B_1 direct

the steam at the correct angle, on to the second row of moving blades M B_2. After passing through M B_2 with its velocity still more reduced, the steam is directed by the second row of fixed blades F B_2 on to the third row of moving blades M B_3. The steam passes from M B_3 into the condenser. Note that no drop in pressure

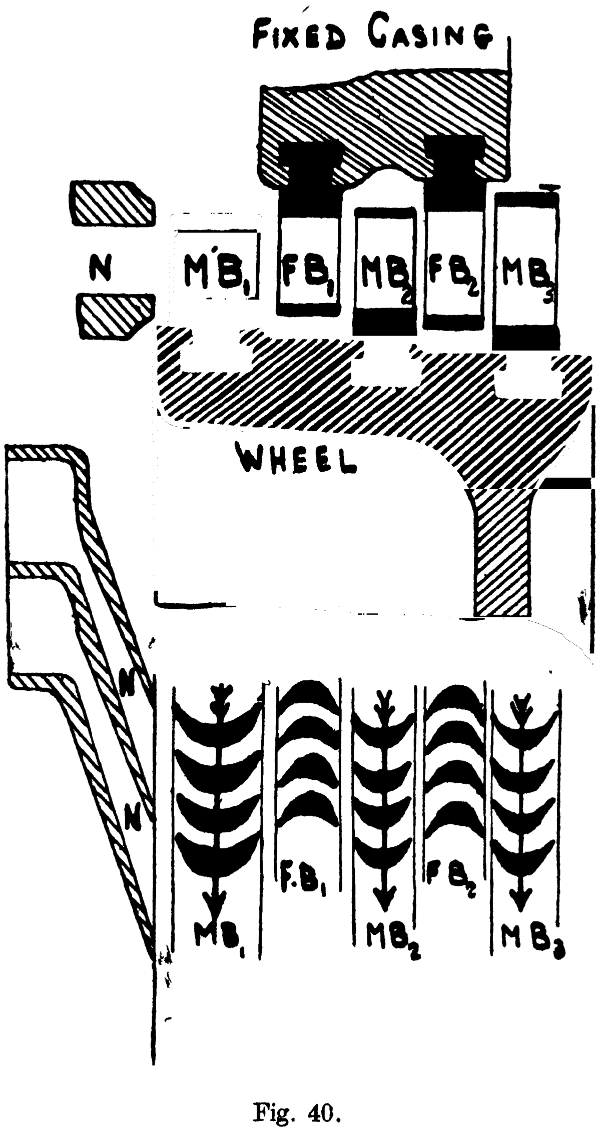


Fig. 40.

DIAGRAM OF VELOCITY COMPOUNDED IMPULSE TURBINE.

occurs either in the fixed or moving blades, the steam being expanded through its total fall in pressure in the nozzles N. There are three velocity stages shown here, the number of stages being the same as the number of rows of moving blades. This turbine, for the same pressure drop in steam and for the same diameter of wheel would run at about one-third of the speed of the De Laval wheel. Generally, if n is the number of velocity stages, the speed of the wheel is $\frac{1}{n}$ of the speed of the simple wheel carrying only one row of moving blades.

PRESSURE COMPOUNDING AND VELOCITY COMPOUNDING COMBINED. In the velocity compounded type, a decrease in the blade speed can be obtained by reducing the nozzle velocity of the steam. This means that the steam must be expanded in a number of pressure stages, each pressure stage being velocity compounded. Thus instead of expanding the steam in one set of nozzles from the boiler pressure to the condenser pressure, and using this steam at a very high velocity, the expansion of the steam is carried

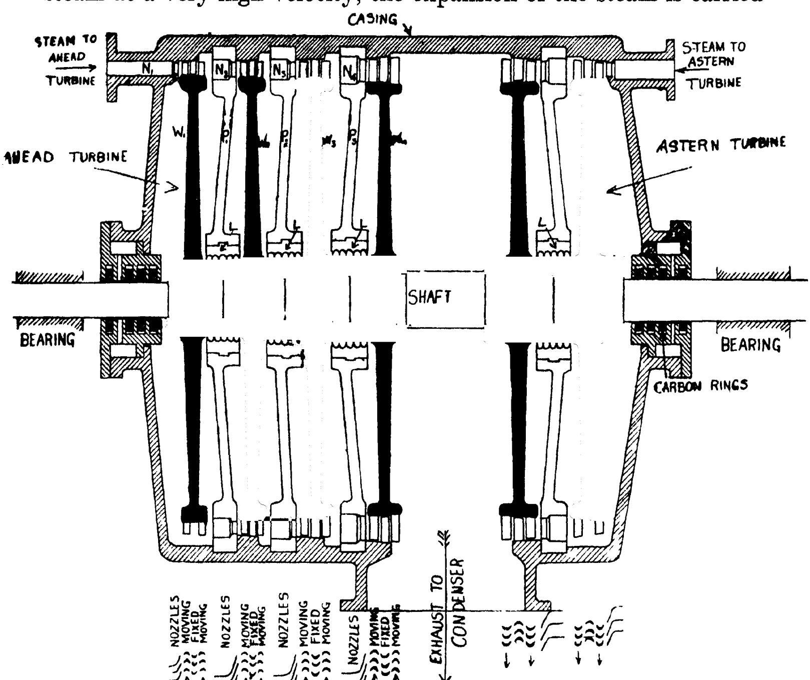


Fig. 41.

DIAGRAM OF COMBINED PRESSURE AND VELOCITY COMPOUNDED IMPULSE TURBINE.

out in a series of stages, each stage consisting of an arrangement of nozzles and a velocity compounded wheel, these wheels all being on the same shaft. The pressure drop in each series of nozzles is much less than when only one set of nozzles is used, and hence the velocity of the steam is less. It follows that for the same diameter of wheel, a much slower speed of revolution can be obtained. The speed of the blades can be reduced in fewer stages by velocity compounding, than by pressure compounding, and this means a small machine. The Curtis turbine is of the pressure-velocity-compound type.

REVERSING. A separate turbine is required for reversing. It is apparent that the flow of steam through blades and nozzles cannot be reversed. The astern turbine is fitted to the same shaft as the ahead turbine ; and therefore it rotates idly with the shaft when going ahead ; under these conditions it is important that the astern turbine should rotate in a medium of small density, so that the power absorbed from the ahead turbine to drive it is very small. When going ahead the idle astern turbine rotates in a mixture of low pressure steam and air, the pressure of which is the same as the pressure in the condenser. Similarly, when going astern, the idle ahead turbine rotates in the low pressure steam, and the power taken to rotate the idle turbine is small.

Fig. 41 shows diagrammatically the arrangement of a pressure-velocity compounded reversing impulse turbine of the Curtis type. There are four pressure stages, and four wheels in the ahead turbine. The pressure drop in each of the four nozzles will be such, that equal quantities of heat are converted into work by each wheel. Each wheel carries two rows of moving blades, and there is one row of blades fixed to the casing, projecting inwards between the rows of moving blades. The wheels are mounted and fixed on to a stepped shaft. The wheels are steel forgings, the shaft being of mild steel. The fixed nozzle plates P_1, etc., are made in two halves, i.e., they are cut through a diameter. The bottom halves are firmly fixed into the lower portion of the casing, the upper halves being fixed into the top part of the casing. The nozzles plates are usually made of cast iron. The nozzles are formed by steel plates swept to the correct shape. These steel plates are inserted into the mould, and during the process of casting are embedded in the metal, and form the nozzles in the nozzle plates.

The labyrinth packing L consists of a series of thin rings almost touching the bosses of the wheels. This packing prevents leakage between the pressure stages. The shaft passes through glands in the ends of the casing, and is made tight by an arrangement of carbon rings.

Each wheel carries two rings of moving blades, so altogether there are eight velocity stages shown in the ahead turbine.

In Fig. 41, high pressure steam enters the nozzles N_1, where it is expanded; the velocity increasing as the pressure falls. The steam, at a high velocity, now enters the first row of moving blades on wheel W_1. In passing through the moving blades the steam loses velocity; after leaving the first row of moving blades, the steam passes into the row of fixed blades which direct it on to the second row of moving blades. No fall in pressure takes place while the steam passes through the blading. After passing through the second moving blades the steam, with greatly reduced velocity, enters the nozzle plate N_2 where a further expansion takes place. Leaving the nozzle N_2 with a velocity about the same as when leaving N_1 the steam now passes through the blading of the second pressure stage, does work in rotating W_2 and enters N_3 with reduced velocity. A further drop in pressure takes place in nozzles N_3 with increase in velocity, the steam then doing work on wheel W_3 in the third pressure stage. Finally the steam again at reduced velocity enters the nozzles N_4 is expanded down to the condenser pressure, gains velocity and does work on the wheel W_4 in the fourth pressure stage, then passes to the condenser.

Reversing is affected by first shutting the steam stop valve which supplies steam to the ahead turbine, then opening the steam stop valve supplying steam to the astern turbine. The diagram Fig. 41 shows the angles at which the nozzles are set for ahead and astern. For going astern two pressure stages only are shown. This means that about one-half of the ahead power is available for going astern. This is perhaps sufficient, as moderate speeds only are needed for astern movements. In the type of impulse turbine just discussed, when applied to propulsion of ships, gearing is needed to reduce the high speed of revolution.

REACTION TURBINES. It has been stated that the name " impulse turbine " is given to that type of turbine in which the expansion of the steam takes place in the fixed nozzles, no fall in the pressure of the steam occurring in the moving blades. In the pure reaction turbine, all the expansion of the steam takes place in the moving blades, and it is the reaction to the issuing jet of steam which propels the blades in the opposite direction. There are no pure reaction turbines in use. The type of turbine in use which is called the " reaction turbine," is more correctly defined as the **IMPULSE REACTION TURBINE.** This turbine is generally called the " Parsons turbine " after the Hon. Sir Charles Parsons, to whom its development is due. The rings of blades on the rotor project into, and rotate in the annular spaces between the rings of fixed blades. Thus there are alternate rings of fixed and moving blades throughout the whole length of the turbine.

A diagram of a Parsons' type reaction turbine is shown in Fig. 42, It consists of a casing which carries rings of fixed blades projecting radially inwards, and a rotor fixed to the shaft. Fastened rigidly into the rotor are the rings of moving blades. The steam enters

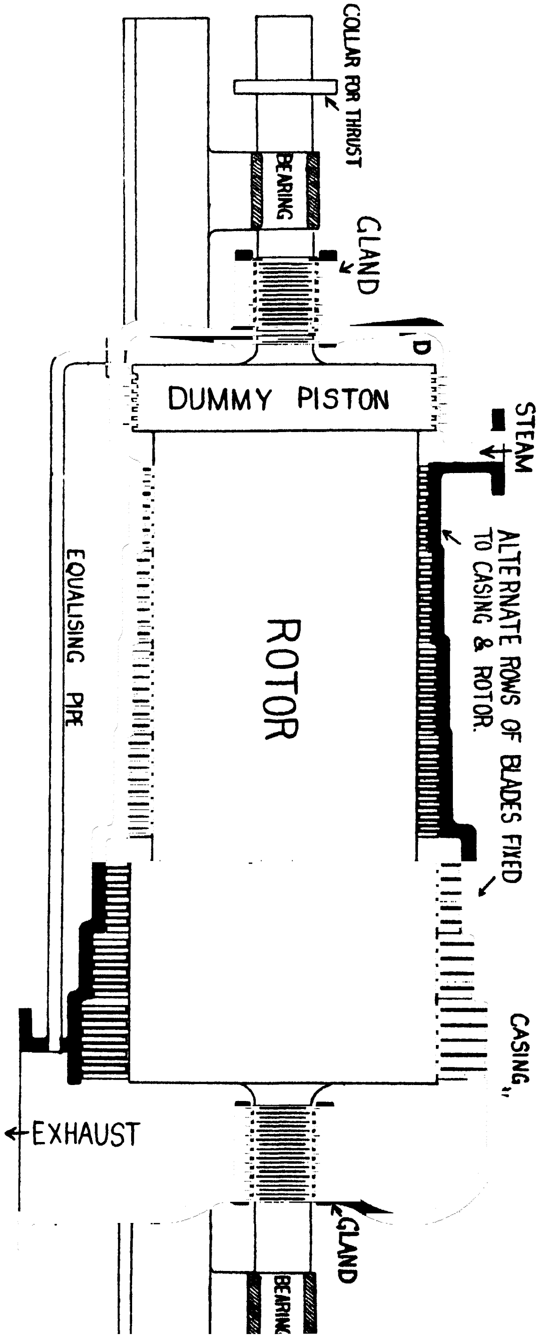


Fig. 42.
DIAGRAM OF PARSONS REACTION TURBINE.

the casing at S, passes through the first row of fixed blades where it suffers a small reduction in pressure. Leaving the first row of fixed blades the steam, now with considerable velocity, is directed on to the first ring or row of moving blades, the effect being that of impulse. The steam now expands in the moving blades, from which it issues at high velocity, exerting a force in the opposite direction to its flow, the effect being that of reaction. This operation is repeated throughout the whole number of rows of fixed and moving blades, the steam, at low pressure, finally passing from the exhaust into the condenser. As the steam falls in pressure, its volume increases, and the annular space between the rotor and the casing must be able to accommodate it. This is done by increasing the diameter of the casing and making the blades longer. As there is a fall in pressure in every ring of blades, the blades in succeeding rings might be made slightly longer ; this would mean making every ring of a different diameter, and as there are a great number of rings this would be inconvenient. In the diagram seven stages are shown. In each stage the length of the blades is the same, and this is more convenient in manufacture. In the impulse turbine as there is no fall in pressure in the moving blades, there is therefore equal pressure in the two sides of the wheels, and no end thrust is delivered to the shaft. In the reaction type, on account of the pressure being higher on one side of the moving blades than on the other, the steam exerts an end thrust on the rotor and shaft. To partly balance this end thrust, **DUMMY PISTONS** are used. The steam in its passage through the turbine exerts a force along the shaft towards the exhaust end. The dummy piston has one face exposed to the action of the high pressure steam. The other face of the dummy piston is exposed to the action of low pressure steam by means of the equalising pipe shown in Fig. 42. The pressures are so arranged that the thrusting force of the steam on the blades added to the force on the face D, shall just equal the force on the other face. A thrust of the Michell type, having one collar takes any unbalanced end force ; the thrust is also necessary to keep the rotor in the correct fore and aft position, for the clearance between the fixed and moving rings is small. Fore and aft adjustment of the rotor is required at intervals. The dummy piston is made steam-tight by means of labyrinth packing, which consists of thin concentric rings of brass projecting from the casing into grooves in the dummy piston, the clearances allowed being very small. Steam glands are provided where the shaft leaves the casing. In the impulse turbine there is a considerable difference in pressure on the two sides of the fixed nozzle plates, and the shaft must be made steam tight where it passes through the nozzle plates. In the Parsons' type, because of the difference in pressure on the two sides of every ring of blades, the steam tends to escape over the tips or ends of the blades. The blades are arranged to have very fine tip clearance ; they are thinned down to a fine edge at the tips, so that if they touch the casing when rotating, the blade ends will

be merely burred over, and " stripping " or pulling out of the blades from their grooves will not occur. The steam leakage depends here upon the " tip clearance," and is more likely to occur at the high pressure end. Another method is to fit a shroud completely round the blades, and to arrange only a very fine axial or end clearance ; with this arrangement fine tip clearance are not necessary.

Turbines of all types are used ashore for the purpose of generating electricity. The high speed of revolution at which dynamos may be driven makes the turbine eminently suitable as a prime mover. Further, the rotating parts are easily balanced, and this reduces vibration to a minimum. The turning moment exerted by a turbine on its shaft does not vary during a revolution, and a steady torque or turning moment is desirable for driving dynamos. Turbines for such purposes are made to rotate in one direction only.

MARINE PRACTICE. When first applied to marine propulsion, the turbine shaft was coupled directly to the propeller shaft, the arrangement being called the " direct drive " system. This system was not an efficient one. The speed of revolution at which the turbine can be run for the best economy, is much too great for the propeller to work efficiently. A compromise was generally effected. whereby the turbine was run at a speed less than its best speed, and the propeller was run at a speed higher than the speed for its best efficiency. To keep the speed of revolutions as low as possible, the turbine diameters were large, and machines of the direct drive system were large and heavy.

GEARED TURBINES. In this system gear wheels are interposed between the turbine shaft and the propeller shaft. The turbine can be run at a high speed, and by means of gear wheels the propeller shaft can be run at the desired speed.

SINGLE REDUCTION SYSTEM. In the single reduction system a large wheel, having double helical teeth, is firmly secured to the main shaft. The expansion of the steam is carried out either in two turbines, the H.P. and L.P. working on separate shafts, or in three turbines, H.P., I.P. and L.P. working on three separate shafts. The turbine shafts have small pinions fixed to them, and these pinions gear into the main gear wheel on the main shaft. Fig. 43A is a diagram of such an arrangement.

In Fig. 43A, the arrangement is shown in plan. The H.P. turbine pinion *a*, engages the main gear wheel *d* on the top, while the I.P. and L.P. turbine pinions *a*, engage the main gear wheel at the starboard and port sides as shown. Sometimes the H.P. and I.P. turbines are on one continuous shaft, with the L.P. turbine on a separate shaft ; in this case two pinions only are needed. The wheels are shown with double helical teeth ; as the angle of the two sets of teeth on each wheel are in opposite directions there is no end thrust due to the gearing. Great accuracy is needed in the

cutting of the teeth. The pinions on the turbine shafts are cut in the solid shaft. The main gear wheels may be of cast iron or built up of steel plates, but in all cases the rim in which the teeth are cut is of special nickel steel. The rim is shrunk on and secured by pins, the teeth being cut in the rim after shrinkage. The turbine pinions are of nickel chrome steel. A flexible coupling C connects the turbine shaft to the pinion shaft, and if by any chance these shafts are slightly out of line, this coupling prevents distortion and stress. Such a coupling is necessary because the pinion shaft runs at a very high speed, speeds from 2,000 to 3,000 revs. per minute being common. The gear wheels are entirely enclosed in an oil tight casing, and oil under pressure is sprayed on to the teeth just before contact, by small pipes.

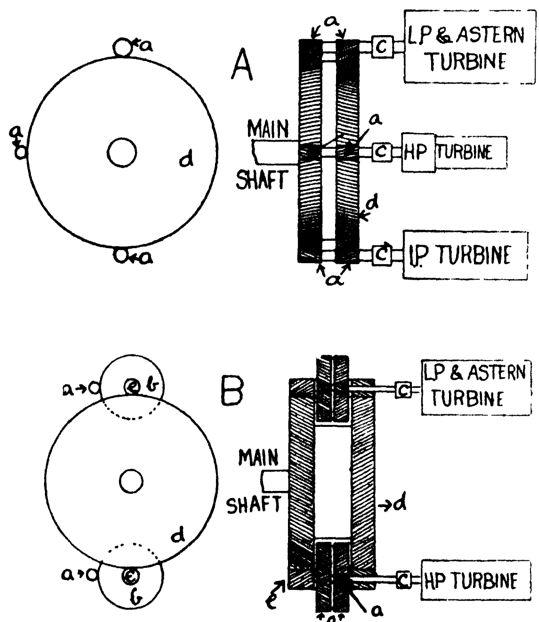


Fig. 43.

DIAGRAM OF : A—SINGLE REDUCTION GEARING.

B—DOUBLE REDUCTION GEARING.

In Fig. 43A, the astern turbine is shown incorporated in the L.P. turbine casing. As already explained, when going ahead the rings of blades on the astern turbine rotate idly. To go astern, the steam is shut off from the H.P. turbine, and high pressure steam is admitted to the astern turbine.

DOUBLE REDUCTION GEARING. When a greater reduction in speed is desired than can be obtained by using the single reduction system, double reduction is used. In Fig. 43B, the pinion *a* on the turbine shaft gears into the second motion wheel *b*. A pinion wheel *e* is firmly fixed to the same shaft as the wheel *b*, the two rotating together. The pinion wheel *e* gears into the main wheel *d*. The system is analogous to the double purchase motion used in a winch.

In this system, very high turbine speeds may be employed, while the propeller shaft can be run at the same speeds as usually obtain in reciprocating practice.

ECONOMY OF TURBINES. Turbines of modern design with reduction gearing, are more economical than triple and quadruple expansion reciprocating engines. A good quadruple reciprocating engine should consume about 1·3 pounds of coal per shaft horse power per hour. A geared turbine should use about 0·9 pound of coal per shaft horse power per hour. The better performance of the turbine is due to the fact, that the steam can be expanded down to a lower pressure than is possible in the reciprocating engine.

In the reciprocating engine the steam is expanded in the L.P. cylinder to about 8 lb. per square inch absolute, then it is released to the condenser where the pressure is about 2 lb. per square inch absolute. To expand the steam down to the pressure of the condenser, would require a low pressure cylinder more than twice the usual volume, and further the steam must be exhausted through a port of limited dimensions. The weight of the moving parts in so large a cylinder, the larger area of cylinder to be heated and cooled by the steam as its temperature changes, and the added friction, make such a design prohibitive. In the turbine, the steam can be expanded down to the pressure in the condenser ; there is no objection to the increase in volume of the L.P. turbine casing, and there is no restriction of area as the steam passes to the condenser. The large area of the parts does not very much increase the friction, and any one part of the casing is always at the same temperature.

This is the explanation of why the turbine can take advantage of a higher vacuum (that is a lower back pressure) than can the reciprocating engine. Hence the importance of being able to maintain a high vacuum in turbine installations.

Turbines are sometimes used in conjunction with reciprocating engines. Instead of the steam from the low pressure cylinder being exhausted direct to the condenser, it is taken to a low pressure turbine where it can do extra work. By this means the efficiency of the propelling machinery may be improved by about 20 per cent.

The work done by the turbine may be applied to the main shaft in two ways. In one arrangement, the turbine helps to drive the shaft through double reduction gearing as shown in Fig. 43 (b). A flexible clutch is included in the arrangement. Another system has a generator driven by the turbine and the electrical power thus obtained is led to a motor on the shaft.

LUBRICATION OF TURBINES. Oil is led to the turbine bearings from a tank situated at a considerable height above the bearings. The height of these oil tanks is sufficient to give a pressure of about 15 lb. per square inch to the oil as it enters the bearings. After passing through the bearings the oil is collected, passed through a filter and so cleaned, then pumped up by a force pump into the overhead tanks, from which it again flows by gravity into the bearings.

The gears are lubricated by means of a similar system, which may be quite separate from the system which oils the white metal bearings of the turbine shaft.

SHAFT HORSE POWER. When a twisting moment is applied to a shaft, the shaft twists through a definite angle. By measuring the angle of twist in a shaft of known length, the value of the twisting moment can be found. An instrument, known as a " torsion meter" is used for this purpose. The angle of twist can be observed and read from this instrument and the shaft horse power can be calculated from the angle of twist. In the turbine, as the twisting moment does not vary throughout one revolution, this instrument is always used. In the reciprocating engine, the indicator is used to give the indicated or cylinder horse power. As some of this power is lost in friction, the shaft horse power is less than the indicated horse power.

ADVANTAGES OF TURBINES. When compared with reciprocating steam engines the advantages claimed for turbines are :—

Greater economy of fuel, due to there being no initial condensation, and because more heat can be taken from the steam. Absence of vibration, due to the fact that there are no heavy reciprocating parts, and that it is comparatively simple to balance rotating masses. Superheated steam can be used to great advantage, because there are no parts in rubbing contact which are exposed to the hot steam, and there is no difficulty about internal lubrication, since oil is not needed internally. There are no moving oil cups such as are needed

on crossheads and connecting rods in reciprocating steam engines. There is no impact on the shaft bearings, as in the case of reciprocating engines at the ends of the stroke, and there is less wear on the bearings.

CLOSED FEED SYSTEM. High pressure steam turbine installations with water tube boilers almost always have a Closed Feed System. The essential point about such a system is that the feed water from the condenser does not come into contact with the outside air before being returned to the boiler. Water will absorb air, and the oxygen in the air may cause severe corrosion in the boiler. In this system the air which finds its way into the condenser, due to small leaks, and the condensed steam are drawn from the condenser separately. The air ejector usually has three stages. A steam jet is directed into a tube and extrains the air with it. The discharge from the first tube enters the second one with its steam jet and so on through the last tube which discharges into the atmosphere. The path of the feed water from the condenser to the boiler is as follows :—A condensate pump draws water from the bottom of the condenser and discharges it through the air ejector on the outside of tubes through which the ejector steam and the air pass. The water condenses the steam used by the ejector, and this condensed steam passes through drains, either back to the condenser or to the reserve feed tank. From here the feed water passes through a drain cooler to the main feed pump which discharges through feed heaters to the boiler.

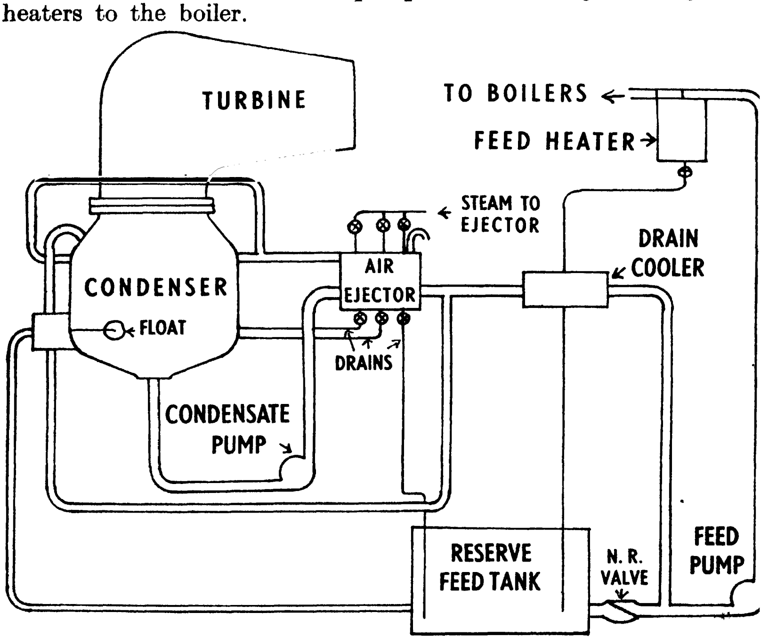


Fig. 44. Closed Feed System.

CHAPTER VII.

THE DIESEL ENGINE.

Two forms of heat engines have already been described, namely the steam reciprocating engine and the steam turbine. It has been explained that heat, which is one form of energy, is evolved by the combustion of fuel in the furnace of the boiler ; and this heat, or a part of it, is carried to the engine in the steam which it uses. Unavoidable losses of heat must occur, the greatest being in the funnel gases of the boiler and in the condenser of the engine.

THERMAL EFFICIENCY may be expressed by the fraction :—

$$\frac{\text{Heat usefully employed}}{\text{Heat supplied}}$$

Applying this expression to the boiler it may be understood as :—

$$\frac{\text{Heat in the steam formed by 1 lb. of fuel}}{\text{Calorific value of 1 lb. of fuel}}$$

and its value will be about 0·7 under the average conditions that obtain in the Merchant Service.

The thermal efficiency of the engine may be understood as :—

$$\frac{\text{Heat equivalent of one horse power hour}}{\text{Heat in the steam used per horse power hour}}$$

The value of this fraction is about 0·17 for a steam reciprocating engine, and 0·24 for a steam turbine, and somewhat higher in the latest modern design.

COMBINED THERMAL EFFICIENCY of a steam engine and boiler is the product of the efficiency of the boiler and the efficiency of the engine. It is approximately $0{\cdot}7 \times 0{\cdot}17 = 0{\cdot}119$, or 11·9 per cent., in the case of the reciprocating engine; and $0{\cdot}7 \times 0{\cdot}24 = 0{\cdot}168$, or 16·8 per cent. in the case of the steam turbine. These efficiencies may be improved upon, but only to a relatively small amount, and it must be admitted that a steam engine is not an efficient machine when viewed from this standpoint.

Within comparatively recent years another form of heat engine has been employed to propel ships, one wherein the fuel is burnt in the cylinder of the engine itself, and which has a thermal efficiency much more than that of the most efficient steam plant. This is the internal combustion engine, and large units, of several thousand horse power, may have thermal efficiencies of 0·34, or 34 per cent. Up to the present this type has been developed only as a reciprocating engine ; and most of the engines made are single acting engines, that is, the working fluid acts on one side of the piston only.

As a consequence of combustion taking place in the cylinder of the engine, very high temperatures are produced in that cylinder, and to prevent injury to the metal of the cylinder and to permit of efficient lubrication of the piston, some of the heat must be abstracted. In large engines it becomes necessary to cool the cylinder, the cylinder head and the piston by circulating water around, or through these parts, and this portion of the heat of combustion, in amount about 30 per cent., is lost. The exhaust gases pass away from the cylinder at a high temperature and constitute a further considerable loss of heat ; but in many modern internal combustion engines, these gases are passed through a boiler and generate steam, and this steam is used to drive auxiliary machinery, such as the steering engine, dynamos or pumps, or for heating cabins, etc. In all internal combustion engines, the working fluid is atmospheric air, and the fuel which heats it is an inflammable gas, or oil in the form of a vapour.

FOUR STROKE CYCLE, may be represented thus :—

First down stroke, Charging First up stroke, Compression	One revolution	One cycle.
Second down stroke, Power stroke Second up stroke, Exhaust	One revolution	

This refers to a vertical engine, but it is equally applicable to a horizontal cylinder engine, and it is seen that there is only one power, or working, stroke in every two revolutions of the engine.

TWO STROKE CYCLE. The down stroke of the piston, or its out stroke in the case of a horizontal engine, is the power stroke. At about the end of this stroke provision is made, in a manner to be explained later, for the escape of the exhaust gases and the recharging of the cylinder. The up stroke, or in stroke, is the compression stroke, and this is followed by a power stroke. The cycle of events is completed in two strokes, or one revolution of the engine, and there is one power stroke every revolution.

All internal combustion engines work on either the four stroke cycle, or the two stroke cycle, whether the fuel used is a light oil (petrol), a medium oil (paraffin) or a heavy petroleum distillate (Diesel oil) ; but the manner in which the fuel is burnt and the heat is evolved is not the same in all of them.

Charles' Law states that the pressure of a gas varies directly as its absolute temperature when the volume remains unchanged. Also, that the volume of a gas varies directly as its absolute temperature if the pressure does not change. If then we imagine a closed vessel containing air, and heat is given to this air by the combustion of fuel, its temperature will rise, and its pressure must increase because the volume cannot change. In these circumstances the heat is said to be supplied under **CONSTANT VOLUME** conditions.

Again, if we imagine air to be enclosed in a cylinder, fitted with a piston subjected to a constant pressure, say that of the atmosphere, when heat is given to the air in the cylinder its temperature will rise, and its volume will increase, because the pressure does not alter. In this case heat is said to be given under **CONSTANT PRESSURE** conditions. If is therefore possible to supply the heat, by the combustion of the fuel, in the cylinder of an internal combustion engine under constant volume conditions, or under constant pressure conditions. Engines working either on the two stroke cycle or on the four stroke cycle, may be designed to receive heat either at constant pressure or at constant volume.

Further, it is possible to supply the heat partly at constant volume and partly at constant pressure. Some internal combustion engines operate under these conditions, and they are two cycle engines.

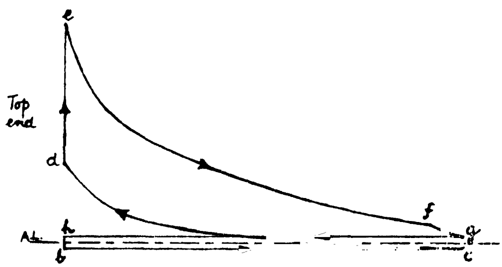


Fig. 45.

COMBUSTION AT CONSTANT VOLUME IN A FOUR CYCLE ENGINE. Referring to Fig. 45, A L is the atmospheric pressure line. A charge, consisting of the fuel for the working stroke and the air to burn this fuel, is drawn in from *b* to *c* by the action of the piston moving along its stroke. The inductive effect is shown by the pressure being a little below atmospheric pressure. This constitutes the first stroke of the cycle. The change is now compressed by the return of the piston, the pressure rising as shown by the ascending curve *c d*. This is the second stroke of the cycle, and at the point *d* the pressure is about 80 lb. per sq. inch. The compressed charge is now fired, usually by an electric spark, complete combustion of the charge and the evolution of heat being practically instantaneous and whilst the piston is stationary at the top of its stroke. Air is the working fluid of an internal combustion engine, and in this type heat is supplied to the air at constant volume. Therefore the pressure rises, indicated by *d e*. At *e* the pressure may be about 200 lb. per sq. inch. The piston is forced down the cylinder on the third stroke of the cycle, the pressure falling as shown by the descending curve *e f*. At *f* the spent gases are allowed to escape from the cylinder and at the end of the stroke the pressure is a little above atmospheric pressure, shown by *g*. The piston returns on the last stroke of the cycle, driving the remains of the gases from the cylinder, shown by the line *g h*. The cycle then re-commences.

This engines requires two valves, an **INLET VALVE** and an **EXHAUST VALVE.** The valves are opened at the correct instant in the cycle of operations by cams, shaped to keep them open for the correct period. Strong springs close the valves when the cams go out of action.

A heavy **FLYWHEEL** is essential to store energy on the working stroke, and to keep the engine running at a uniform speed during the remaining three strokes.

The fuel used may be a gaseous fuel, such as town gas, or petrol, or paraffin. The first need not be considered further since it is not available for marine work, but the other two may be used in the engines fitted to a motor lifeboat. Liquid fuels must be vaporized and mixed with air to form the charge drawn into the cylinder on the first stroke. This is the function of the carburetter, and very briefly this consists of a small jet or orifice arranged in the induction pipe leading to the inlet valve. A float controls the level of the fuel in this jet. When the inlet valve opens, the action of the air sweeping through the induction pipe into the cylinder also draws the necessary fuel from the jet. If petrol is used this vaporizes very readily and forms the gas-air charge. If paraffin is employed the carburetter is heated to assist vaporization and the exhaust gases may be used for this purpose. Motor lifeboat engines, or the engines of the emergency electric generating set may be started up on petrol and changed over to paraffin when the engine has attained the necessary temperature.

COMBUSTION AT CONSTANT VOLUME IN A TWO CYCLE ENGINE. Fig. 46 is a diagram of this engine and Fig. 47 represents the change of pressure occurring during the cycle.

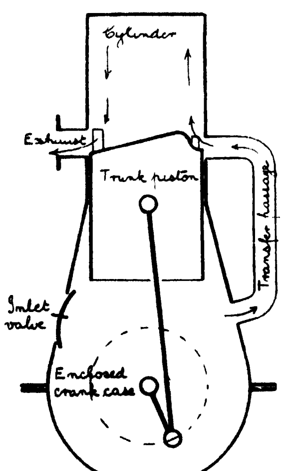


Fig. 46.

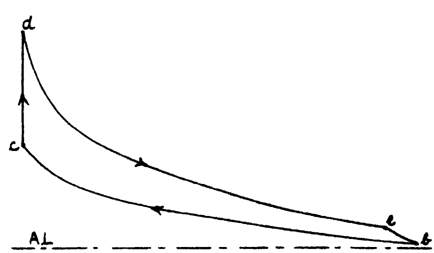


Fig. 47.

The cylinder has two ports, or two rows of ports near its lower end, one set extending rather further up the cylinder barrel than the other. These are the exhaust ports. The others lead by means of a passage—the transfer passage to the crank case, which is constructed to be pressure tight against moderate pressures. There is an automatic inlet valve on the crank case leading from the carburetter. Consider the piston at the top of the stroke. Combustion has taken place and the pressure has risen to *d* (Fig. 47). The piston is forced down the cylinder and the pressure gradually falls as indicated by the curve *d e*. At *e* the piston has completed enough of its stroke to uncover the exhaust ports and the spent gases escape to the atmosphere, the pressure in the cylinder falling still further. Now, as the piston descends the volume of the enclosed crank case is reduced and the pressure in this space has increased to 2 or 3 lb. per sq. inch above the atmospheric pressure. Very shortly after the piston uncovers the exhaust ports, it also uncovers the ports leading to the crank case. The gaseous contents of the crank case pass into the cylinder through the transfer passage, and the piston head is shaped to deflect these gases towards the top of the cylinder; they therefore assist in clearing the cylinder of the spent gases. The gaseous contents of the crank case are the charge for the next working stroke. The piston completes its stroke, and in rising on the next stroke it first closes the transfer ports, then the exhaust ports, compression begins and continues throughout this stroke, as shown by *b c* Fig. 47. At the end of the up stroke the compressed charge is fired and the pressure rises as shown by *c d*.

On the up stroke the piston acts in a manner similar to the bucket of a pump, inasmuch that it reduces the pressure in the crank case causing the inlet valve to open and admit a further charge of oil gas and air mixture from the carburetter into the crank case, this charge being compressed slightly in the crank case when the piston descends on its working stroke.

THE DIESEL ENGINE is a form of internal combustion engine which receives its heat, from the combustion of the fuel, under constant pressure conditions. It may be a four cycle engine or a two cycle engine.

COMBUSTION AT CONSTANT PRESSURE IN A FOUR CYCLE ENGINE. Referring to Fig. 48, A L is the atmospheric pressure line. On the first stroke of the cycle **AIR ONLY** is drawn into the cylinder, the pressure being a little below atmospheric pressure as indicated by the line *b c*. When the piston returns on the up stroke this air is compressed to a pressure of about 500 lb. per sq. inch, the rise of pressure and the second stroke of the cycle being shown by the ascending curve *c d*. Owing to the work done upon the air during compression it attains a temperature of about 1000° F. by the time point *d*, and therefore the end of the up stroke, is reached. The fuel oil, in the form of a fine spray, now begins to enter the

cylinder and, mixing with this very hot air, it burns, generating heat. But the rate of entrance of the fuel into the cylinder is controlled by the design of the fuel valve, so that, as the piston moves down the cylinder on the third stroke, sufficient heat is generated to maintain a constant pressure on the piston. This is indicated by *d e* in Fig. 48. At *e* about one tenth of the third stroke kas been completed and the injection of the fuel ceases. The generation of heat stops and as the piston continues its stroke the pressure falls, this being indicated by the descending curve *e f*. At *f* the spent gases are allowed to escape to the atmosphere by the opening of the exhaust valve, the pressure drops to *g*. On the fourth, and last stroke of the cycle the ascending piston drives the remaining gases from the cylinder, shown by *g h*, and the cycle recommences. This en-

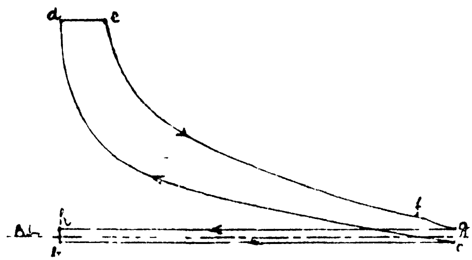


Fig. 48.

gine requires an **INLET VALVE ; A FUEL VALVE ; AN EXHAUST VALVE.** These valves are opened at the correct point in the cycle by cams shaped to keep them open for the desired period, and they are closed by the action of strong springs when the cams go out of action. An **AIR STARTING VALVE** is necessary also. This is opened by a cam and admits compressed air from the air storage vessels, at a pressure of about 350 lb. per sq. inch, to start the engine. A **RELIEF VALVE** is essential, and this is atuomatic in its action. All the valves are situated in the cylinder cover, or cylinder head.

Fig. 49 is purely diagrammatic, and represents the parts of a four stroke Diesel engine.

AIR INLET VALVE admits air into the cylinder from the engine room.

EXHAUST VALVE allows the spent gases to escape through a silencer to the atmosphere.

FUEL VALVE has to perform the following functions. To begin injection of the fuel at the correct time, and to continue injection at the correct rate to ensure constant pressure.

To break up the fuel into a fine spray.

To distribute the fuel to all parts of the combustion space.

To deliver the correct amount of fuel.

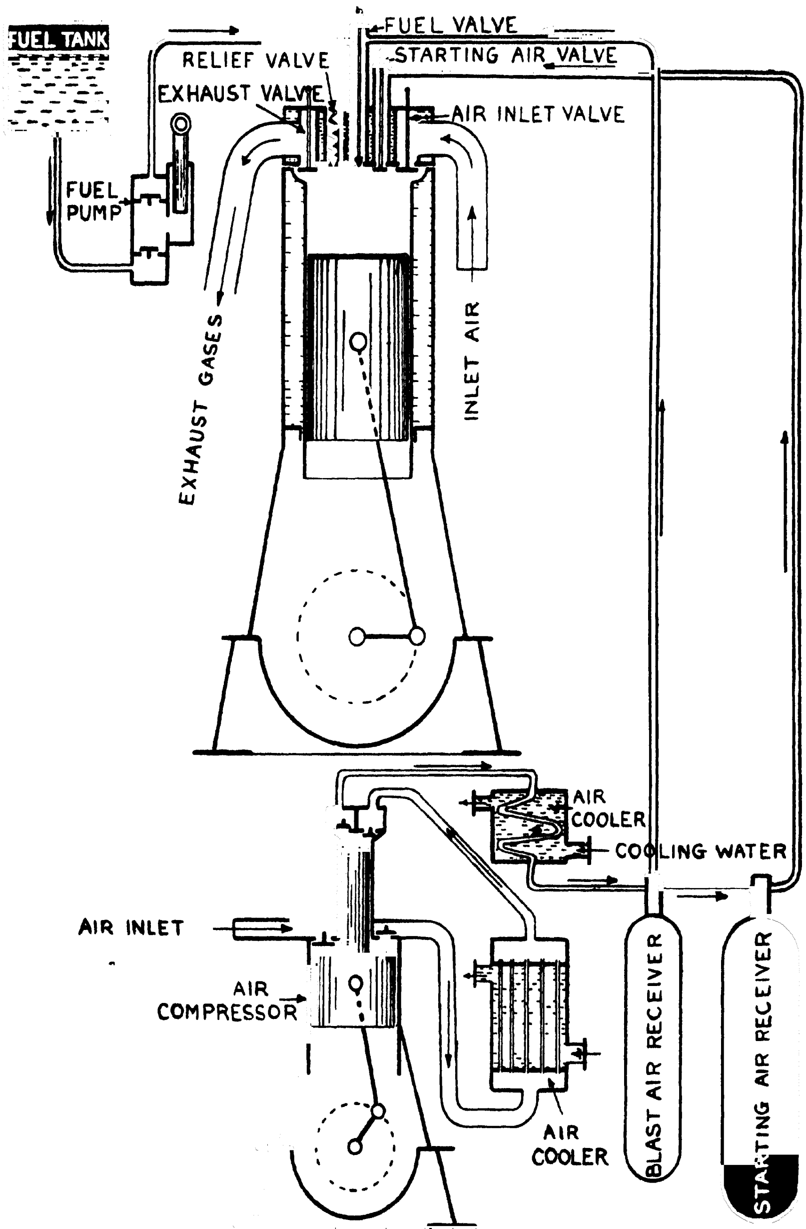


DIAGRAM OF FOUR STROKE DIESEL ENGINE

Fig. 49.

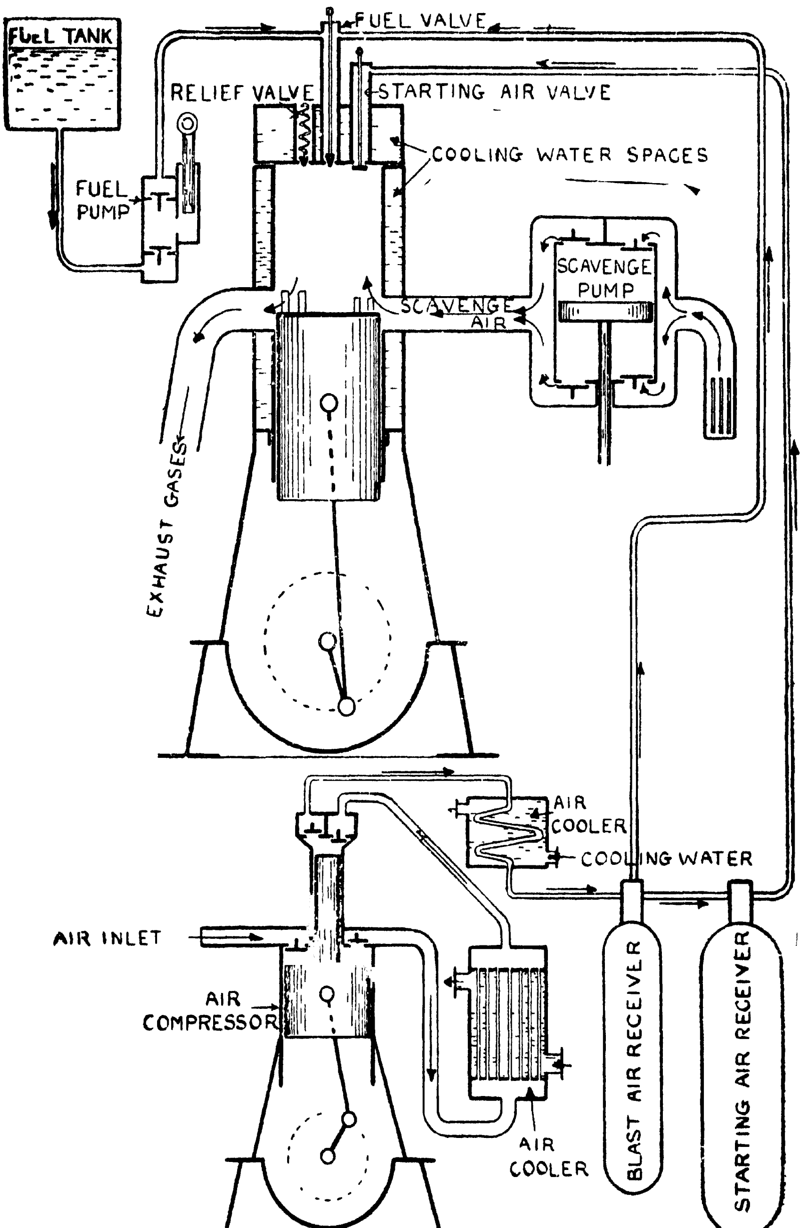


DIAGRAM OF TWO STROKE DIESEL ENGINE

Fig. 50.

Two methods of injection of the fuel are employed. In one the fuel is forced into the cylinder by air at a pressure of about 1,000 lb. per sq. inch. This method is generally called **BLAST INJECTION** or injection by means of air. The injection air is supplied by an air compressor driven by means of levers from the crosshead of one of the engines, or by a crank on the crank shaft. An independent air compressor, driven by a separate engine, is also necessary to maintain the air pressure in the air storage bottles when the engines are being manœuvred.

The other method of fuel injection is to force the fuel into the cylinder, through a number of very small openings in the spray plate, by subjecting the fuel to a pressure of several thousand pounds per sq. inch. This is **AIRLESS INJECTION,** sometimes referred to as **SOLID INJECTION,** and most modern types of Diesel engines employ this method.

COMBUSTION AT CONSTANT PRESSURE IN A TWO CYCLE ENGINE. The cylinder liner is arranged with two rows of ports

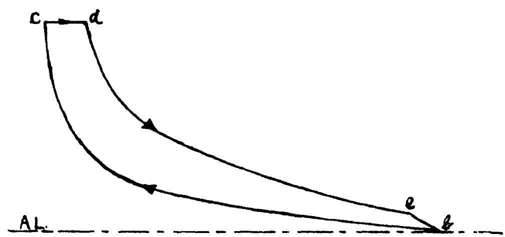


Fig. 51.

at its lower end. One set extend further up the cylinder barrel than the other. These are the exhaust ports, the others are the scavenge ports. The piston is sufficiently long to entirely cover both sets of ports when it is at the top of its stroke. (See Fig. 50).

Imagine the piston at the top of its stroke. Air has been compressed in the cylinder on the up stroke to a pressure of about 500 lb. per sq. inch, causing its temperature to reach about 1,000° F. The fuel valve is opened and fuel oil is injected by air blast, or by mechanical pressure, into this hot air. The fuel burns, evolving heat, but the rate of injection is such that a constant pressure is maintained in the cylinder for about one-tenth of the down stroke. This is shown by *c d* (Fig. 51). At *d* the fuel valve closes, fuel injection and the supply of heat cease, and as the piston descends the pressure falls as indicated by the curve *d e*. At *e* about 0·85 of the stroke has been completed and the piston uncovers the exhaust ports. This allows the spent gases to pass to the atmosphere through the silencer and the pressure to fall to nearly atmospheric pressure. At about 0·9 of the down stroke the piston uncovers the scavenge ports and clean air, at a pressure of about 3 lb. per sq. inch above

the atmospheric pressure, passes into the cylinder and sweeps out the remaining burnt gas, thus "scavenging" the cylinder. The scavenge air is supplied by a double acting air pump, which is driven by levers, or by a crank off the main engines, and the capacity of the scavenge pump is about 1½ times the capacity of the engine cylinders. This is in order to ensure thorough scavenging of the cylinders.

As the piston ascends on the next stroke, it first closes the scavenge ports, then the exhaust ports, compression of the air in the cylinder takes place as shown by the ascending curve *b c*. At *c* fuel injection takes place and the next cycle of events commences.

The valves essential to this type of engine are a fuel valve, an air starting valve and a relief valve. They are situated in the cylinder cover, or head, and each cylinder requires one of each.

The fuel valve and the air starting valve are opened by the action of cams keyed on the cam shaft, the cams being suitably shaped to keep the valves open during the desired period. They are closed by the action of springs when the cam peaks are out of action. The relief valve is automatic in its action and opens if the pressure in the cylinder reaches an abnormal amount.

THE MARINE DIESEL ENGINE has generally three or more cylinders in line. It may be a vertical single-acting engine, either four stroke or two stroke. Or a vertical double-acting engine (i.e., with combustion taking place on both sides of the piston), either four stroke or two stroke. Or a vertical opposed piston engine working on the two stroke cycle.

A marine Diesel engine must be :—

(1) Capable of running in either direction.

(2) Able to start, stop or reverse quickly and with certainty and have a considerable range of speed variation.

(3) Capable of running for long periods at full power.

The manner in which each of these conditions of service is attained will be briefly dealt with.

METHOD OF REVERSAL. The valves necessary for four cycle and two cycle engines have already been mentioned. The valves are opened by levers and push rods actuated by cams on the cam shaft, and the cam peaks are suitably shaped, and set, in order to open their respective valves at the correct instant in the cycle and to keep them open for the required period. The cam shaft, upon which the cams are fixed, has its axis parallel to the axis of the crank shaft from which it is driven by spur gearing, or in some cases by chain drive. The cam shaft of a two cycle engine runs at the same number of revolutions per minute as the crank shaft, but the cam shaft of a four cycle engine has a speed one-half that of the crank shaft. There are two cams for each valve, placed side

by side, one cam to operate the valve when running ahead, the other to operate it when running astern, and the required cam is brought under the roller of the actuating lever by sliding the cam shaft the necessary distance in the fore and aft direction.

The operation of reversal may be described as follows :—

The first movement of the reversing wheel puts the fuel valves out of action and the engine slows down. Further movement first lifts the push rods clear of the cams and then shifts the cam shaft so that the cams for the reverse direction of rotation are in position. The push rods are returned to their normal working position and the air starting valve cams are in operation, but not the fuel valve cams. Compressed air from the starting air receivers enters the cylinders and acts on the pistons in a manner similar to the action of steam in a steam engine and the engine starts. Continued movement of the reversing wheel puts the starting air cams out of operation and brings the fuel valve cams into operation and the engine continues to run under its own power. It is essential that mechanism is provided to ensure that the fuel valves and air starting valves are not in operation at the same time.

METHOD OF STARTING. Since the Diesel engine depends upon the heat of compression for firing the fuel, it must first be set in motion by outside means, and compressed air is always used for this purpose. The air is compressed by an air compressor driven by the main engines, and it is stored in large steel cylindrical receivers of capacity sufficient to give at least twelve starts without refilling. An independently driven air compressor is always installed to replenish the receivers when the main engine is stationary. Figs. 49 and 50 show two stage air compressors diagrammatically. Air is drawn in from the engine room into the L.P. cylinder of the compressor and it is compressed to about 100 lb. per sq. inch, becoming hot in the process. It then passes through the tubes of a cooler around which sea water is circulated. The air is thus cooled and then passed to the H.P. cylinder, where its pressure is increased still further and it is again cooled before passing to the receiver. Most modern air compressors have three stages of compression, or even four.

The compressed air for starting purposes is admitted to the cylinders of the main engine by the air starting valves. The period of opening of these valves depends upon the number of cylinders. The cycle of operations of a four stroke engine is completed in two revolutions, or 720° angular movement of the crank shaft. If this engine has six cylinders, the starting valve of each cylinder would be actuated by a cam shaped to keep it open for $\frac{720^\circ}{6} = 120^\circ$ movement of the crank shaft at least, and it should open shortly after the crank passes the top centre on the working stroke of the cycle. In this manner certainty of starting, from any position, is ensured. A six cylinder two cycle engine would have its air starting valves arranged to open for not less than $\frac{360^\circ}{6} = 60^\circ$ of the crank movement.

STOPPING THE ENGINE. Suitable mechanism is provided by means of which the suction valves of the fuel pumps are held off their seats. This prevents the fuel pumps from discharging fuel to the casing of the fuel valves and the engine comes to rest. Automatic governors are generally fitted to marine Diesel engines to check heavy racing. These act through a system of levers on the suction valves of the fuel pumps, and either prevent the pumps from discharging fuel, or reduce the quantity of fuel pumped.

REGULATION OF SPEED. There are different ways in which this is attained, but the method most generally used is to vary the quantity of fuel delivered to the fuel valve each working cycle. In most engines, each cylinder has its own fuel pump, worked by an eccentric, or other gear, from the cam shaft. A fuel pump is a small single acting force, or plunger pump. The up stroke of the plunger is the suction stroke, the down stroke is the delivery stroke. The fuel pump delivers fuel to the casing of the fuel valve, from whence it enters the cylinder when the fuel valve is opened.

On the up stroke of the fuel pump plunger the chamber of the pump fills with oil. When the plunger returns this oil is displaced through the delivery valve if the suction valve is closed, but through the suction valve and back to the fuel tank if the suction valve is open. By providing suitable mechanism to keep the suction valve open for varying periods of the discharge stroke of the fuel pump, the quantity of oil delivered to the fuel valve is varied, with consequent variation of the power output and the speed of the engines.

FEATURES OF THE MARINE DIESEL ENGINE. The capacity of a marine Diesel to operate for long periods at full power can only be attained by soundness in its design and suitability of the materials used in its construction. The cylinders and cylinder liners, the cylinder covers or heads and the pistons and their rings are made of special cast iron which has a tensile strength of 15 to 18 tons per sq. inch.

The cylinder liners are held down in place in the cylinder casting by a spigot on the cylinder head. They are not fixed at their lower ends, so that they have freedom to expand. The space between the cylinder liner and the cylinder casting constitutes the water jacket through which water is circulated when the engine is in operation.

The cylinder head is of deep section and hollow. It has pockets into which the various valves are fitted. Water is circulated through the cylinder head to maintain the temperature of this casting at a safe working temperature. Either sea water, or fresh water is used in circulating liners and heads. If fresh water is used, it circulates in a closed cycle, through the liners and heads thence to a large tank to be cooled and returned to the circulating system.

Sea water is liable to deposit sediment and form scale in the various passages of the castings. This leads to overheating and the possible failure of that part.

The pistons are cooled by fresh water, or in some cases by having oil circulated through them. The cooling fluid may reach the piston head by way of a hole bored through the piston rod and parallel to its axis, and return in a similar manner. Telescopic tubes are sometimes employed instead. In the diagrams Figs, 49, 50 trunk pistons are shown, but these are not used for marine Diesel engines of large power. The invariable practice is to have a piston rod and crosshead, with double guides, similar to the reciprocating steam engine.

Piston rods and connecting rods are mild steel forgings, and all the principal bearings are lined with white metal. The crank shaft is built up in a manner similar to the construction of the shaft for a steam engine.

METHOD OF LUBRICATION of all the large bearings is automatic. A hole is bored axially along the crankshaft, meeting with a hole drilled radially at the main bearing journal. The crank pin is likewise drilled axially and then radially, these passages being connected by a hole bored down the crank web. Oil is supplied, under pressure, by a pump to the main bearings. Some of the oil lubricates this bearing, the remaining passes through the passages mentioned to the crank pin, and effects the lubrication of this bearing. The surplus oil passes up a hole bored in the connecting rod to the top end brasses. The oil which escapes from the various bearings drains to a sump in the crank case, from whence it is drawn by the pump through filters and coolers and again returned to the bearings.

LUBRICATION OF THE PISTONS. A small pressure lubricator, worked by the main engines, forces oil through a number (about six) small holes drilled through the cylinder liner near its lower end, the discharge of oil being timed to occur when the piston is at, or about, the bottom of its stroke. A special oil, having a high flash point, is used, and provision is made by means of a diaphragm plate to prevent this oil from falling into the crank case and so contaminating the lubricating oil. Piston lubricating oil becomes dirty and partly carbonised, and is unfit for further use.

OVERHAULS AND ADJUSTMENTS. All bearings must be periodically cleaned and adjusted, and their oil-ways cleared.

Pistons are frequently withdrawn for cleaning and the inspection of their rings. Leaky piston rings would not only allow gases to pass to the engine room, but they would affect the compression and possibly cause the engine to missfire.

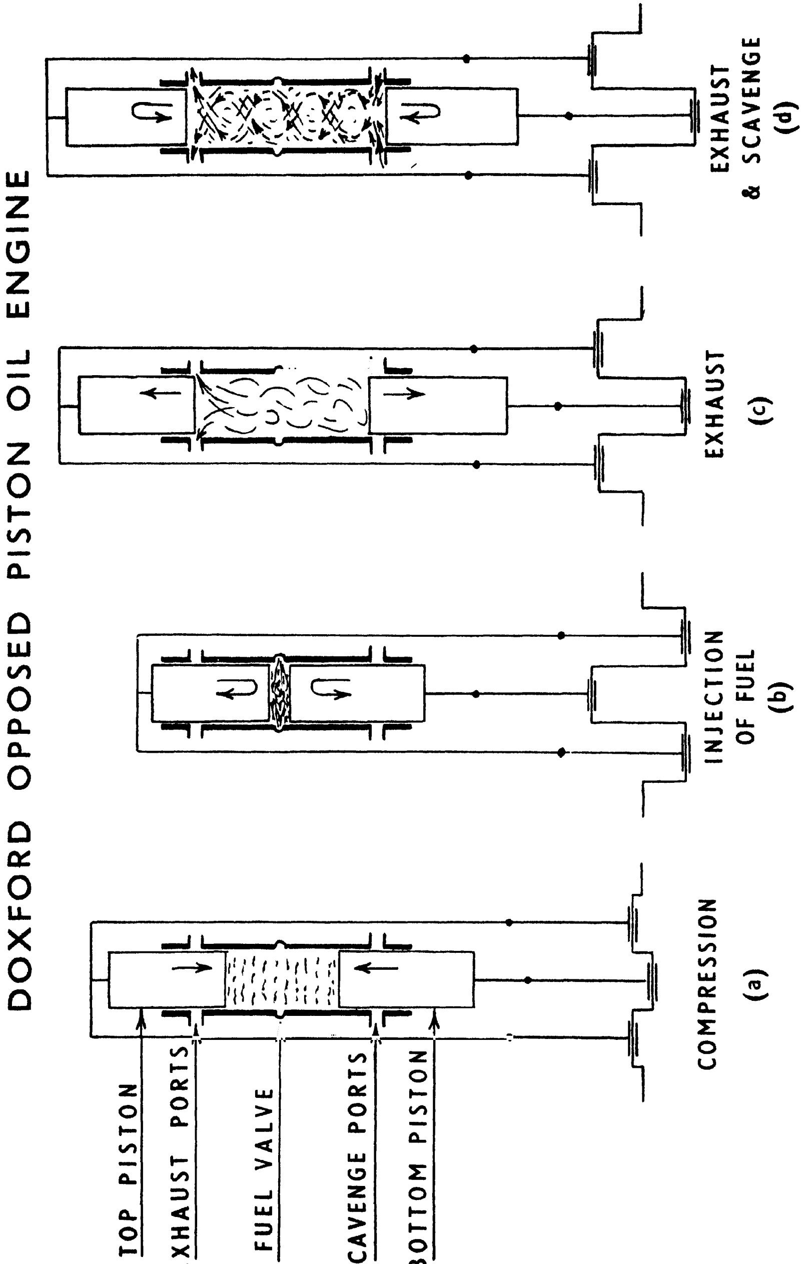

DOXFORD OPPOSED PISTON OIL ENGINE
TOP PISTON
EXHAUST PORTS
FUEL VALVE
SCAVENGE PORTS
BOTTOM PISTON
COMPRESSION
(a)
INJECTION OF FUEL
(b)
EXHAUST
(c)
EXHAUST & SCAVENGE
(d)

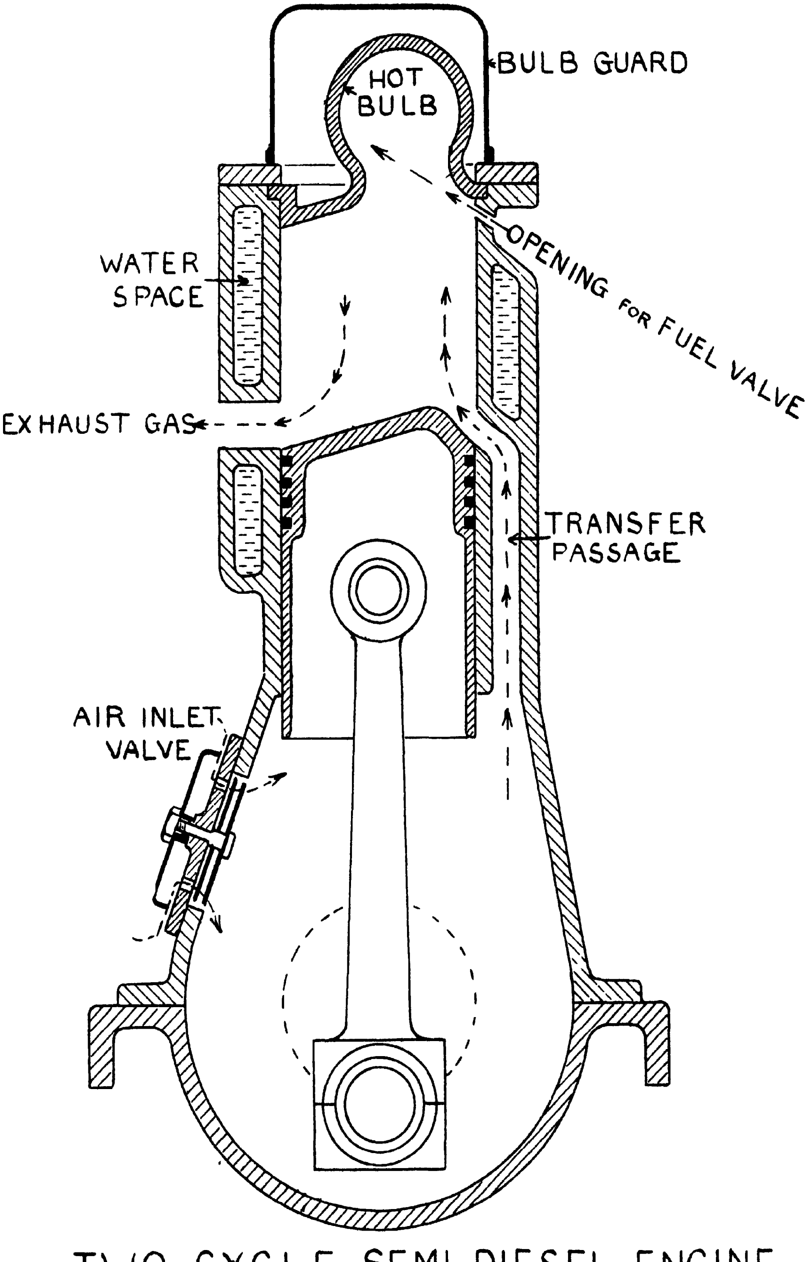
Fig. 52.

All the valves must be examined, ground in and tested at frequent intervals. Spare valves are always ready at hand to replace any valve that develops a defect whilst the ship is at sea. The exhaust valves are subjected to the very high temperature of the gases during exhaust, and these require attention and replacement at shorter intervals than the other valves.

THE DOXFORD OPPOSED PISTON OIL ENGINE has two pistons in each cylinder, the lower piston is connected to the centre crank, and the upper piston to two side cranks, the side cranks are at 180 degrees to the centre crank so that the movement of the pistons is opposite to each other. Scavenge air enters through a row of ports near the bottom of the cylinder, fuel is injected in the centre of the cylinder, and the burnt gases exhaust through a row of ports near the top. Referring to Fig. 52, diagram (a) shows air being compressed as the two pistons approach each other. Diagram (b) shows the pistons at the innermost parts of their strokes, cranks on their dead centres, air has now reached a very high temperature partly due to compression and partly due to heat given out from an uncooled portion of each piston ; fuel is injected, burns immediately and gives out heat which is converted into work driving the pistons on their outward strokes. In diagram (c) the exhaust ports are being uncovered by the top piston, this is the beginning of exhaust, the scavenge ports will shortly be uncovered by the bottom piston. In diagram (d) the pistons are at their outermost parts of their strokes, cranks on their dead centres, scavenge air is entering the bottom ports driving out the burnt gases through the exhaust ports at the top. As the pistons come together, both sets of ports will be covered up, compression of the air will commence and the cycle of operations repeated.

A SEMI-DIESEL ENGINE is a type of internal combustion engine wherein a charge of liquid fuel is injected, in the form of a fine spray, into a combustion space open to the cylinder and at about the instant of maximum compression. Ignition is brought about partly by the heat of compression and partly by the temperature of the combustion space, which is uncooled. Combustion of the fuel takes place under approximately constant volume conditions.

The combustion space is generally called the " hot bulb," and Fig. 43 is a diagrammatic section of such an engine. Before starting, the bulb is heated by a blow lamp to the necessary temperature, and when working the bulb is maintained at this temperature by the heat of combustion, the blow lamp being removed. Referring to Fig. 53 the piston is shown at its lowest position. Air is entering the cylinder from the enclosed crank case at a pressure a little in excess of the atmospheric pressure, driving the spent gases of the previous working stroke from the cylinder. When the piston rises, it closes the transfer and exhaust passages and the air in the cylinder



TWO CYCLE SEMI-DIESEL ENGINE.

Fig. 53.

is compressed to about 150 lb. per sq. inch. At, or about the top of the stroke, fuel is sprayed into the hot bulb. Combustion occurs and the heat evolved causes the pressure to rise to about 300 lb. per sq. inch and the piston moves down on the power, or working stroke. It should be noted that as the piston moved up on the compression stroke it reduces the pressure in the crank case causing the air inlet valves to open and admit air into the crank case. This air is compressed to a pressure a little greater than the atmospheric pressure when the piston moves down on the working stroke. The piston uncovers the exhaust and transfer passages, which allows the exhaust gases to escape to the atmosphere and the cylinder to be scavenged by the air from the crank case. The cycle is then repeated.

Engines of this type, coupled to dynamos, or air compressors are often employed in motor vessels. Semi-Diesel engines are very often used as the propelling motors of small vessels. In this case the engine may have two, or more cylinders each developing approximately 100 H.P.

It is very evident that this type of engine, which has no valves, is capable of running in either direction indifferently. The method of reversal when it is employed as a marine motor is briefly as follows. The engine has been running ahead and it is required to reverse the direction of rotation. The main fuel pump is cut out and the engine slows down. When the speed has reduced sufficiently, the auxiliary fuel pump is brought into action. This pump is timed to inject a charge of fuel into the hot bulb considerably before the piston reaches the top centre on the compression stroke. Pre-ignition occurs, starting the engine in the astern direction, and also cutting the auxiliary pump out and bringing the main fuel pump into action and the engine continues to run astern. Reverse from astern to ahead is effected in a similar manner. The fuel used may be paraffin or Diesel oil.

CHAPTER VIII.

PROPULSION OF SHIPS.

The resistance to propulsion is made up of :—

Frictional resistance.
Eddy making resistance.
Wave making resistance.

FLUID FRICTION. Fluid friction depends upon the condition of the surface exposed to the liquid.

Fluid friction varies as the total immersed area.
,, ,, varies as $(\text{velocity})^n$.
,, ,, is independent of the fluid pressure.

The friction force varies directly as the area exposed to the fluid, and varies directly as $(\text{velocity})^n$; these two rules are important. The value of n is often taken as 2, a more correct value is **1·83,** and this value refers to clean, painted surfaces. These rules were deduced by Froude from experiments.

Froude found experimentally that a force of 0·25 lb. is required per square foot of wetted surface at a speed of 600 feet per minute, a speed which is roughly 6 knots.

For moderate speeds, say up to 10 knots, the frictional resistance is the greatest part of the total resistance. There are many rules for estimating the approximate wetted surface of a vessel. Denny's rule is easy to apply :—

Wetted surface in square feet $= 1{\cdot}7\ L\ D + \frac{V}{D}$, where L is the length in feet, D is the draught in feet and V is the under water volume in cubic feet.

CO-EFFICIENT OF FINENESS, or the block co-efficient, is a measure of the fineness of the under water form of the vessel, and is

$$\frac{\text{Volume of under water part of ship}}{\text{Volume of circumscribing prism}}$$

$$= \frac{\text{Displacement of ship in cubic feet}}{\text{Length} \times \text{Breadth} \times \text{Draught}}$$

and, Displacement in cubic feet $= L \times B \times D \times$ block co-efficient.

Displacement in tons $= \frac{L \times B \times D \times \text{block co-efficient}}{35}$, in salt water.

Example. A vessel is 400 feet long, 52 feet beam and 25 feet draught, the co-efficient of fineness being 0·75. Find the displacement in tons. This vessel is to be driven at 12 knots, find the total wetted surface and the total frictional resistance, allowing 0·25 lb. at 6 knots.

$$\text{Displacement} = \frac{400 \times 52 \times 25 \times 0{\cdot}75}{35} = 11{,}143 \text{ tons. Ans.}$$

$$\text{Wetted surface} = 1{\cdot}7\,L\,D + \frac{V}{D}$$

$$1{\cdot}7 \times 400 \times 25 + \frac{400 \times 52 \times 25 \times 0{\cdot}75}{25}$$

$$= 17{,}000 + 15{,}600 = 32{,}600 \text{ square feet. Ans.}$$

Taking the friction force varying as V^2.

Frictional resistance $= 32{,}600 \times 0{\cdot}25 \times (\frac{12}{6})^2 = 32{,}600$ lb. Ans.

EDDY MAKING RESISTANCE. When a square ended box barge is towed through the water, there is a great disturbance of the water at the bow and along the sides of the fore end. At the after end there is a greater disturbance. due to the rushing of the water round the square corners of the stern. These confused currents of water are called " eddies " or " dead water," and they produce a great resistance to the motion of the barge. Eddy making resistance depends mostly on the shape of the under water form of the vessel, and in full ships with bluff bows and sterns, may amount to a considerable value. In fine lined vessels with block co-efficients not exceeding 0·75, the eddy making resistance is a small proportion of the total resistance. It is important that under water appendages such as propeller brackets, etc., in twin screw ships, should be carefully stream-lined in shape.

In addition to the eddying of the water round any sharp corners or blunt terminations of parts of the hull, eddying which occurs under the water and also at the surface, there is a wave making resistance produced by the form of the vessel and the speed ; a resistance which takes the form of waves on the surface of the water.

WAVE MAKING RESISTANCE. As the ship moves through the water bow waves are generated, waves which move forward at an oblique angle to the direction of the ship's motion ; these waves, after leaving the bow, have no further effect on the progress of the ship. Another set of waves is produced, and these waves have their crests at right angles to the fore and aft line of the ship, their arrangement into crests and troughs along the sides of the ship being well defined. The lengths of these waves from crest to crest depends upon, and has a definite relation to, the speed of the ship. The length of the wave is found to vary directly as the square of the speed of the ship. This means that as the speed of the ship is increased, the

length between the crests of these waves becomes much greater. For every form of hull there is a speed which should not be exceeded; for if this correct speed is exceeded, the resistance to motion caused by these transverse waves becomes very great, and the propulsion of the ship cannot be economically performed. At low speeds the wave resistance is a small proportion of the total, but at high speeds it becomes of great importance, and is a considerable proportion of the total resistance.

The eddy making and wave making resistances are generally combined, and form what is called the "residual wave resistance." The actual values of the frictional and residual resistances are determined by means of suitable models towed in a large tank at the proportional speed.

The proportional speed, or the corresponding speed, is the speed at which to tow the model, so that the transverse wave produced bears the same relation to the length of the model, as the wave produced by the ship bears to the length of the ship.

THRUST HORSE POWER. Approximately, from 40 to 50 per cent. only of the indicated horse power is available at the thrust. This means that about 50 per cent. of the total power is used in doing work which is not propelling the ship. The horse power at the thrust is often called the tow rope or the thrust horse power, and this is the power to apply externally by means of a tow rope to give the required speed.

Example. Find the indicated horse power needed to propel the vessel in the previous example, if only 50 per cent. of the I.H.P. is available at the thrust. Assume that the frictional resistance is 78 per cent. of the total resistance.

$$\text{Now horse power} = \frac{\text{Work done per minute in foot lb.}}{33{,}000}$$

And work done per min. = force in lb. × feet per minute.

$$= 32{,}600 \times \tfrac{100}{78} \times \frac{12 \times 6080}{60} \text{ ft. lb.}$$

$$\text{Horse power at thrust} = \frac{32{,}600 \times 100}{78} \times \frac{12 \times 6080}{60 \times 33{,}000}$$

Horse power = 1,540.
I.H.P. = 1,540 × $\tfrac{100}{50}$ = 3,080. Ans.

RELATION BETWEEN SPEED AND HORSE POWER.

$$\text{Since Horse Power} = \frac{\text{Force} \times \text{distance in feet per min.}}{33{,}000}$$

Then Horse Power varies as Force × distance in unit time, and as in comparing horse powers the figure 33,000 will be common

to all, and because we measure speed not in feet per minute, but in " knots," the knot is used as the distance gone in unit time, unit time being one hour.

Horse Power varies as Force × S, where S is speed in knots.

Now the Force varies as $(\text{Speed})^2$,

Hence Horse Power varies as $(\text{Speed})^2 \times S$

or Horse Power varies as $(\text{Speed})^3$.

Now the consumption of fuel varies directly as the horse power, therefore :—

Consumption varies as $(\text{Speed})^3$.

It should be stated that at very high speeds, the consumption varies as the speed raised to a power somewhat higher than 3, but for merchant vessels steaming at ordinary speeds the value 3 is generally used.

Note that to increase the speed from 10 to 12 knots will increase the consumption in the ratio of $(\frac{12}{10})^3$ or 1·728, that is the consumption is increased 72·8 per cent.

If the speed be decreased from 10 to 8 knots, the consumption is decreased in the ratio of $(\frac{8}{10})^3$ or 0·512, that is $\frac{1 - 0{\cdot}512}{1} \times 100 = 48{\cdot}8$ per cent. This is the explanation of the saving of coal at reduced speed.

The statement, consumption varies as $(\text{Speed})^3$, refers to time, or :—

Consumption per day varies as $(\text{Speed})^3$.

Now two quantities vary directly when their quotient is constant.

This means that $\frac{\text{Consumption}}{(\text{Speed})^3} = \text{constant}$,

$$\text{or } \frac{(\text{Consumption}_1)}{(\text{Speed}_1)^3} = \frac{(\text{Consumption}_2)}{(\text{Speed}_2)^3}$$

$$\text{or } \frac{\text{First consumption}}{\text{First (Speed)}^3} = \frac{\text{Second consumption}}{\text{Second (Speed)}^3}$$

Example. A vessel steams at 10 knots indicating 2,200 I.H.P. What I.H.P. is required to drive the vessel at 11 knots ?

Since the I.H.P. varies as $(\text{Speed})^3$ we can write :—

$$\frac{\text{First I.H.P.}}{\text{First (Speed)}^3} = \frac{\text{Second I.H.P.}}{\text{Second (Speed)}^3}$$

$$\frac{2200}{10^3} = \frac{\text{Second I.H.P.}}{11^3}$$

Second I.H.P. $= 2200 \times (\frac{11}{10})^3 = 2928$. Ans.

Example. A steamer runs at 12 knots on 50 tons of coal per day. Find the speed when the consumption is reduced to 35 tons per day.

$$\frac{\text{First consumption}}{\text{First (Speed)}^3} = \frac{\text{Second consumption}}{\text{Second (Speed)}^3}$$

$$\frac{50}{12^3} = \frac{35}{\text{Second (Speed)}^3}$$

Cross multiplying, we get, $50 \times \text{Second (Speed)}^3 = 35 \times 12^3$.

$$\text{or Second (Speed)}^3 = \frac{35 \times 12^3}{50}$$

Taking Logs.

$$\begin{aligned} 3 \times \text{log. of Second Speed} &= \text{log. } 35 + (3 \text{ log. } 12) - \text{log. } 50. \\ &= 1{\cdot}5441 + (3 \times 1{\cdot}0792) - 1{\cdot}699. \\ &= 1{\cdot}5441 + 3{\cdot}2376 - 1{\cdot}699. \\ &= 3{\cdot}0827. \end{aligned}$$

$$\text{Hence log. of Second Speed} = \frac{3{\cdot}0827}{3} = 1{\cdot}0275$$

and log. $1{\cdot}0275 = 10{\cdot}64$

Second Speed is therefore 10·64 knots. Ans.

(Four figure logs. have been used here).

Example. A steamer burns 36 tons of oil fuel per day at 12 knots, find the consumption of oil fuel at 9 knots.

$$\frac{\text{First consumption}}{\text{First (Speed)}^3} = \frac{\text{Second consumption}}{\text{Second (Speed)}^3}$$

$$\frac{36}{12^3} = \frac{\text{Second consumption}}{9^3}$$

Cross multiply, $36 \times 9^3 = \text{Second consumption} \times 12^3$.

$$\text{Second consumption} = 36 \times \frac{9^3}{12^3} = 15{\cdot}18 \text{ tons. Ans.}$$

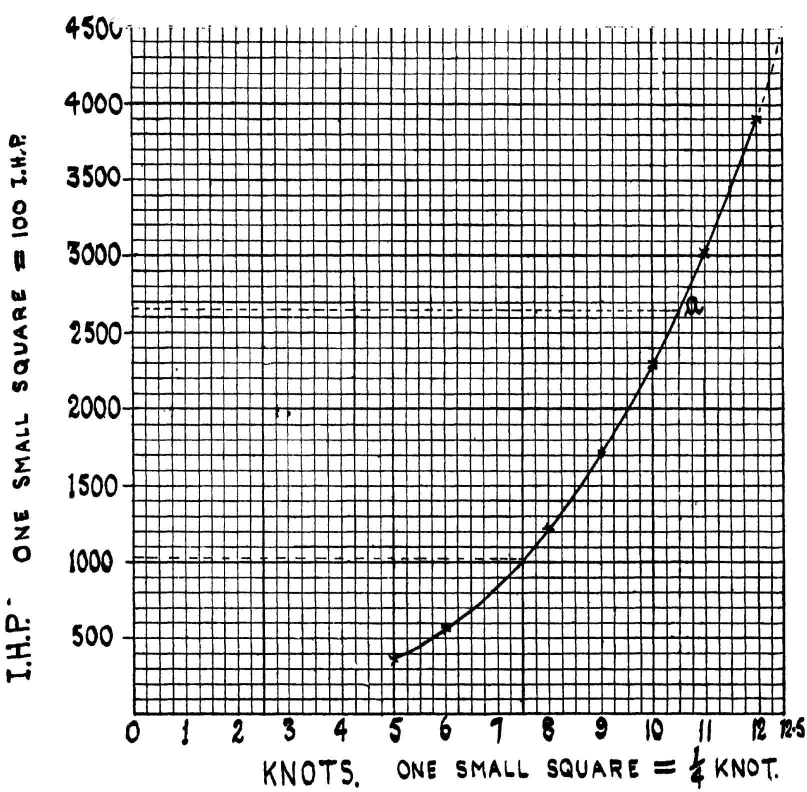
In these problems, it is assumed that the condition of the hull of the ship is the same as regards being clean, and that the weather conditions are identical.

CURVE OF I.H.P. AND SPEED. The following observations were made of the performance of a steamer of 11,000 tons displacement. The I.H.P. was measured by means of an indicator, at the various speeds shown. Thus at 8 knots the I.H.P. was 1,226, at 10 knots the I.H.P. was 2,300, seven such observations being given.

On the diagram shown, Fig. 54, vertical distances represent I.H.P., and horizontal distances represent knots, the scales being written on the diagram. To plot the diagram on squared paper,

first mark off the horse powers from 0 to 4,500, then mark off knots from 0 to 12. At the position of 5 knots, mark a cross at a distance of 3·6 squares above the zero of horse power; this is because at 5 knots the I.H.P. was 360, and as one small square represents 100 I.H.P., then 3·6 squares represent 360 I.H.P. In the same manner plot the other values given, a series of 7 crosses being made. Now draw a smooth curve through the crosses. The curve may be used to find the horse power needed for any speed between the observed values. Thus at 10·5 knots—draw a dotted line vertically upwards

I.H.P.	360	575	1226	1704	2300	3028	3900
KNOTS	5	6	8	9	10	11	12



CURVE OF I.H.P. AND SPEED.

Fig. 54.

to meet the curve, at *a* then draw a dotted line horizontally from *a*, and the horse power is seen to be about 2,650 for 10·5 knots. In the same way, for a speed of 7·5 knots the horse power is seen to be about 1030. This method of obtaining the horse power between observed values is called " interpolating." It is not wise to produce the curve beyond the observed values. At the top of the diagram, curve is shown produced in a dotted line. This gives the horse power at 12·5 knots as 4500. This is called " extrapolating," and the method is not good, because the curve may not take the form suggested by the dotted line, and the horse power at 12·5 knots may be greater than 4,500. In all cases of this kind, the curve should be used within the limits of the observed values, and it is unwise to predict the horse power for speeds above the observed values. For the given vessel, no observations were made below a speed of 5 knots. The sea speed of this ship being 11 knots, consumptions for speeds below 8 knots are not needed, as the vessel will not be run so far from her designed speed.

CONSUMPTION FOR A GIVEN VOYAGE. Consumption per day or per hour varies as $(\text{Speed})^3$.

The consumption, however, for a given distance or voyage varies as $(\text{Speed})^2$.

(*a*) Consumpt. per voyage varies as (Fuel per hour $\times$ hours on voyage),

but fuel per hour varies as $(\text{Speed})^3$.

$$\text{and hours on voyage} = \frac{\text{Distance}}{\text{Speed}}$$

Putting these values in (*a*) we get :—

$$\text{Consumpt. per voyage varies as } \left(\text{Speed}^3 \times \frac{\text{Distance}}{\text{Speed}}\right)$$

or Consumpt. per voyage varies as $(\text{Speed})^2 \times$ Distance, and for the same distance, the consumption varies as the $(\text{Speed})^2$. Note that here the consumption is the total fuel used on the voyage.

Example. A ship steaming at 10 knots is 1,600 nautical miles from port, and has coal for 900 miles only at 10 knots. At what speed must she be run to reach port ?

Consumption varies as $V^2 \times$ Distance.

$$\text{Hence } \frac{\text{Consumption}_1}{V_1^2 \times D_1} = \frac{\text{Consumption}_2}{V_2^2 \times D_2}$$

But here the coal used will be the same

$$\text{hence } V_1^2 \times D_1 = V_2^2 \times D_2$$

$$10^2 \times 900 = V_2^2 \times 1{,}600$$

$$V_2^2 = \frac{100 \times 900}{1,600}$$

$$V_2 = \sqrt{\frac{900}{1,600}} \times 10$$

$$V_2 = \tfrac{30}{40} \times 10 = 7{\cdot}5 \text{ knots. Ans.}$$

Example. A vessel has coal for 6 days at 10 knots, but is 8 days from port if going 10 knots. Find the speed at which to run to reach port.

Here, consumption per day $\times$ time is the same, and as the distance is the same whatever the speed, consumption on voyage varies as (Speed)^2.

Let C be the daily consumption at 10 knots,

Total coal needed for 8 days $= C \times 8$ tons.

Coal aboard is only $= C \times 6$ tons.

$$\frac{(\text{Consumption})_1}{S_1^2} = \frac{(\text{Consumption})_2}{S_2^2}$$

$$\frac{C \times 8}{10^2} = \frac{C \times 6}{V_2^2}$$

Cross multiply $V_2^2 \times C \times 8 = 10^2 \times C \times 6.$

C cancels, $V_2^2 = 10^2 \times \frac{6}{8}.$

$$V_2 = 10 \times \sqrt{\tfrac{6}{8}} = 8{\cdot}66 \text{ knots. Ans.}$$

Example. A ship runs at 10 knots and requires 500 tons of fuel to reach port at this speed. Find the speed at which to run if only 400 tons of coal are available.

Here, as the distance gone at any speed to reach port is the same, consumption per Distance varies as V^2.

$$\frac{\text{Consumption}_1}{V_1^2} = \frac{\text{Consumption}_2}{V_2^2}$$

$$\frac{500}{10^2} = \frac{400}{V_2^2}, \text{ or } V_2^2 = \frac{400 \times 10^2}{500}$$

$$\text{and } V^2 = \sqrt{\tfrac{4}{5}} \times 10 = 8{\cdot}944 \text{ knots. Ans.}$$

Fuel Co-efficient. It has already been stated at the beginning of this chapter that the frictional resistance of a liquid varies as the speed^2 and as the wetted surface.

Horse power varies as the resistance $\times$ speed

and resistance varies as speed^2 $\times$ wetted surface

$\therefore$ H.P. $\propto$ speed^2 $\times$ surface $\times$ speed

$\propto$ speed^3 $\times$ surface.

For any similarly shaped surface, the area varies as the square of the corresponding dimensions, thus the area of a cube twice the size of another cube will be $2^2 = 4$ times the area of the second. This is true no matter what the shapes of objects are as long as they are of the same proportions throughout.

The volume of similarly shaped objects vary as the cube of the corresponding dimensions. Thus if, say, two cones have the same proportions, then the volume of one to the volume of the other will vary as the height of the first cubed is to the height of the second cubed, or as the diameter of the first cubed is to the diameter of the second cubed.

The displacement (D) of a vessel will vary directly as the volume. Therefore, considering ships of similar shape and their lengths :—

$$D \propto L^3 \text{ or } D^{\frac{1}{3}} \propto L$$

$$\text{surface (S)} \propto L^2 \text{ or } S^{\frac{1}{2}} \propto L$$

$$\therefore D^{\frac{1}{3}} \propto S^{\frac{1}{2}} \text{ and } S \propto D^{\frac{2}{3}}.$$

Now consider the statement, $HP \propto \text{speed}^3 \times \text{surface}$

$$\text{and surface} \propto (\text{Displacement})^{\frac{2}{3}}$$

$$\therefore HP \propto \text{speed}^3 \times \text{Displacement}^{\frac{2}{3}}.$$

$$\propto V^3 D^{\frac{2}{3}}$$

$$\therefore \frac{V^3 D^{\frac{2}{3}}}{HP} = \text{a constant.}$$

Consumption per day varies with the HP.

$$\therefore \frac{V^3 D^{\frac{2}{3}}}{\text{Consumption}} = \text{a constant} = \text{the fuel co-efficient.}$$

When a ship changes its draught the proportions of the underwater shape are not similar, and therefore, strictly speaking, the surface does not vary as the displacement$^{\frac{2}{3}}$, but if the change is not great the relation between the qualities given will be approximately true.

Example. The daily consumption of a ship of 12,000 tons displacement is 15 tons when the speed is 11 knots. If 600 tons of cargo are discharged and the voyage is resumed at 10 knots, what daily consumption of fuel might be expected ?

$$\frac{11^3 \times 12{,}000^{\frac{2}{3}}}{15} = \frac{10^3 \times 11{,}400^{\frac{2}{3}}}{C^2}$$

$$\therefore C^2 = 10 \cdot 64 \text{ tons per day.}$$

PITCH OF PROPELLER. The pitch of a propeller is the distance the propeller would advance in one revolution, if working in an unyielding medium. The distance advanced in one revolution is less than the pitch, by an amount called the slip. The slip is always expressed as a percentage of the theoretical speed, that is as a percentage of the speed if the propeller worked in an unyielding medium.

$$\text{Theoretical speed} = \frac{\text{Pitch} \times \text{Revolutions} \times 60}{6{,}080} \text{ knots.}$$

$$\text{Percentage Slip} = \frac{\text{Theoretical Speed} - \text{Speed of ship}}{\text{Theoretical Speed}} \times 100$$

Example. A vessel runs at 14 knots, the pitch of the propeller is 20 feet, and it makes 80 revolutions per minute. Find the precentage slip.

$$\text{Theoretical Speed} = \frac{80 \times 80}{6{,}080} \times 60 = 15{\cdot}79 \text{ knots.}$$

$$\text{Percentage Slip} = \frac{15{\cdot}79 - 14}{15{\cdot}79} \times 100.$$

$$= 11{\cdot}33 \text{ per cent. Ans.}$$

TEST QUESTIONS

CHAPTER I.

1.—What is cast iron ? What parts in engines and ships are made of cast iron ? Give its ultimate tensile and compressive strength.

2.—What is wrought iron ? What are its physical properties ? What is its ultimate strength in tension ? What parts of engines could be made of it ?

3.—What is mild steel ? What are its physical properties ? Compare its strength with that of wrought iron. Give its ultimate strength in tension. Compare its structure with that of wrought iron. What parts of engines and ships are made of mild steel ?

4.—Of what material are ordinary steel castings made ? What parts of engines and ships may be steel castings ?

5.—What tests are made on mild steel (*a*) plate, (*b*) rivets.

6.—Of what material are cutting tools made ? How does this material differ from mild steel ?

7.—State the effect of carbon in steel. What is the percentage of carbon in (*a*) mild steel, (*b*) tool steel ?

8.—Which of the ferrous metals are ductile and which is brittle ?

9.—What is brass ? For what properties is it valued ? What parts may be cast in brass ?

10.—What is muntz metal ? For what parts is it used ? Wherein does it differ from ordinary cast brass ?

11.—What is bronze and where it is used ?

12.—What is white metal ? Where it is used ? What advantages has it for bearings and what disadvantages ?

13.—Write short essays on hand welding; oxy-acetylene welding ; electric welding.

14.—Of what material would you make the following :—An anchor; an anchor cable ; a winch piston ; a split pin ; a bilge valve ; a boiler plate ; a Diesel cylinder liner ; a top end bearing ; a bottom end bearing ; a crank shaft ; the barrel and bucket of a fresh water pump ; a piston rod for the main engine ; a blade for a high pressure turbine ; a tank sounding pipe ; a deck steam pipe ; the head of a hand hammer ; a hand chisel and a drill ?

CHAPTER II.

1.—What are the two main types of boilers used in marine practice ? Give a brief description of the essential parts of one of them.

2.—Make a simple sketch of a section through a multitubular cylindrical boiler, showing the position of the furnaces, combustion chambers and smoke tubes, and show by means of arrows the passage of the gases from the furnace to the funnel.

3.—What shape are modern furnace tubes and why is this corrugated form used ?

4.—What is the function of the various stays used in boilers ?

5.—Why is a manhole made oval ? What is about the size of an average manhole in a boiler ?

6.—Name the parts of a water tube boiler.

7.—Compare the water tube boiler with the Scotch or cylindrical multitubular boiler, stating the advantages and disadvantages of each.

8.—Of what material are modern boilers made ?

9.—For what purposes is a donkey boiler used ? When there is no donkey boiler fitted on board, how is steam supplied for auxiliary purposes in port ?

10.—What is a safety valve ? What is its use and where is it fitted ?

11.—Describe a high lift safety valve.

12.—Where are water gauges fitted on a boiler ? What danger would arise from its neglect ? What attention does this gauge require when under steam ?

13.—Write out a list of the mountings fitted to a boiler, stating the function of each.

14.—What important precaution is necessary before opening out a boiler for internal inspection ?

15. What precautions are necessary before blowing the water completely out of a boiler through the blow down valve ?

16.—What parts would be injured first by overheating, should the water level in a boiler be allowed to get low ?

17.—What is meant by circulating a boiler ? Why is this operation necessary, and how it is performed ?

18.—What is meant by water hammer and what means are adopted to prevent it ?

19.—State the causes of corrosion in boilers.

20.—What is meant by combustion ? State the chief constituents of fuels.

21.—Give the approximate calorific value of good coal. For the same power developed, what extra percentage of Indian coal would be needed compared to good British coal?

22.—What is meant by the "flash point" of oil and what is its approximate value for fuel oils?

23.—What is the calorific value of fuel oils?

24.—State the essential parts of an oil burning system.

25.—Before lighting up an oil fuel burner, air is allowed to pass through the furnace for a while, why is this?

26.—What means are provided for dealing with possible outbreaks of fire in ships using oil fuel?

CHAPTER III.

1.—What is heat? How is temperature measured? What is the unit of quantity of heat?

2.—What is meant by the term absolute temperature?

3.—Define sensible heat and latent heat.

4.—State Boyle's law and Charles' law for perfect gases.

5.—Explain the terms:—Work, horse power, indicated horse power.

6.—What is the advantage of using steam expansively?

7.—What is the important property of gases that makes them useful in heat engines generally?

8.—What is the advantage of using a number of cylinders instead of only one? Define compound expansion, triple expansion, and quadruple expansion.

9.—What is meant by isothermal and adiabatic operations?

10.—What is superheated steam? How is it produced in a boiler and what is its purpose?

CHAPTER IV.

1.—What is a "reciprocating engine"? Name the principal parts of a condensing reciprocating steam engine.

2.—What is a simple steam engine, and what is a compound steam engine? Show by diagrams the arrangement of the cylinders of a triple expansion engine and a quadruple expansion steam engine. Name the cylinders, and indicate by arrows the passage of the steam through the cylinders.

3.—What materials are used for:—Pistons; piston rods; piston packing rings; cylinder liners; junk ring bolts; condenser tube plates; piston rod glands; crank pin bearings; main steam pipes?

4.—Sketch a steam engine piston and state the purpose of the junk ring.

5.—Describe the method of securing a piston to the piston rod. Sketch the arrangement, and show how the nut is prevented from slacking back.

6.—Trace the passage of one pound of steam from the boiler through the engine to the condenser and back to the boiler as water. Name, in order, the chambers or vessels through which the fluid passes.

7.—Write a short description of the construction of a modern crank shaft. Make simple sketches in illustration.

8.—How is the thrust of the propeller transmitted to the hull of the ship ? Describe, briefly, a thrust shaft and thrust block.

9.—Sketch and describe a Michell type of thrust block and state the advantages of this type over the multicollar thrust block.

10. Describe a stern tube, and explain how it is secured in the ship. Name the materials used for the different parts.

11.—How often should a propeller shaft be withdrawn for examination, and why is this necessary ? Briefly describe the method of withdrawal.

12.—What is a steam condenser, and why is it used with a marine engine ? Make a simple sketch of a surface condenser and show by arrows the direction of the steam and of the water.

13.—Sketch and describe the method of packing condenser tubes to prevent leakage of sea water.

14.—What is an air pump ? Explain the action of an Edwards' air pump.

15.—What is the bilge injection valve ? Where is it fitted, and in what circumstances would it be used ?

16.—Describe the process of " warming through " a set of engines and preparing them for sea.

17.—Write a short essay dealing with the duties of the engineer officer of the watch on the main engines.

18.—Steam pipes expand when heated and contract as they cool down. Explain how this expansion and contraction is allowed for.

19.—What attention might be necessary to steam reciprocating engines upon arrival in port after, say, two weeks at sea ?

Answer.—Any bearing that has been noted on the passage to require adjusting should be attended to, and any bearing that has run unsatisfactorily should be lifted and cleaned, and its oilways re-cut if necessary. Glands on the main engines and main engine pumps should have an extra turn of packing inserted if required. The leads of the slide valves may be gauged, and " wear down " corrected by liners of the required thickness inserted under the feet of the eccentric rods. Generally, give attention to those parts which cannot be examined or adjusted whilst the engines are running, to lessen the likelihood of " stoppages " at sea.

CHAPTER V.

1.—Describe the action of a double acting pump.

2.—Describe a centrifugal pump and give examples where it is used.

3.—State the uses of the following pumps :—Main feed pump, circulating pump ; bilge pump ; ballast pump ; general service pump.

4.—What is an evaporator ? State briefly the essential parts of an evaporator.

5.—There are two types of feed heaters ; name them. Why are they fitted and where are they placed ?

6.—What is meant by the term " forced draught," and what are the advantages of using it ?

7.—Describe very briefly a steam steering gear.

8.—What is a telemotor as used on a ship ?

9.—Describe a steam winch. What arrangements are provided for lifting light and heavy loads ?

10.—What damage may be done to deck machinery in very cold climates ? How would you guard against such damage ?

11.—What is the principle of the vapour compression system of refrigeration ? What are the essential parts of the machine, and what are the substances commonly used as the refrigerating agent ?

12.—Of what is the brine composed in a refrigerating system, what is its density and freezing point ? Could sea water be used as a brine ?

13.—Upon what principle does the working of a cold air refrigerating machine depend ? Briefly describe the essential parts of the machine.

14.—Sketch a section through a refrigerated hold of a ship showing details of insulation on the shell and hatch covers.

15.—How is fresh drinking water made from sea water ?

16.—Describe briefly a steam windlass. What care does it need at sea and in port ?

17.—About what is the lifting capacity of a windlass for a 10,000 ton vessel ?

CHAPTER VI.

1.—What is the function of a nozzle in a simple impulse turbine ?

2.—Describe briefly a simple impulse turbine of the De Laval type.

3.—Of what materials are turbine blades made ?

4.—What is meant by pressure compounding and what is its object ? How is the expansion of the steam carried out ?

5.—What is meant by velocity compounding and how does this differ from pressure compounding ?

6.—What methods are used to reduce the high rotational speeds of turbines ?

7.—Describe how impulse blades are fitted to the turbine wheels. Of what materials are casings, blades and wheels made ?

8.—Why is a high degree of vacuum necessary for a steam turbine ?

9.—What arrangements are made for the reversing of marine turbines ?

10.—What are the advantages of turbines ?

11.—Describe briefly the Parson's reaction turbine.

12.—Sketch a closed feed system.

CHAPTER VII.

(Answers to some questions are given).

1.—What are the flash points of petrol, paraffin, Diesel oil ?

Ans.—Petrol about 40° F. to 60° F.

Paraffin must not be below 73° F. The flash point is generally about 100° F.

Diesel oil may not be below 150° F. and is usually about 180° F.

2.—How is the fuel prepared for combustion in engines using petrol, paraffin, Diesel oil ?

Ans.—Petrol is drawn from the jet of the carburetter by the action of the induction air, and, being a very volatile oil, it vaporises and mixing with the air forms the explosive mixture.

In an engine using paraffin as fuel the carburetter may be heated by the exhaust gases to assist in vaporising the oil, or the paraffin may be injected into a hot bulb and so vaporised, as in the semi-Diesel engine.

Diesel oil is atomised by being forced through very small holes in the pulverising rings of the fuel valve, blast air at a pressure of about 1,000 lb. per sq. inch forcing the oil through. Or it may be forced through a number of holes about 0·02 inch diameter in the sprayer, the oil being at a pressure of from 6,000 to 10,000 lb. per sq. inch.

3.—How is combustion brought about in engines using petrol, paraffin, Diesel oil ?

Ans.—Combustion is brought about in a petrol engine by means of an electric spark bridging the gap between the points of the sparking plug. The high tension current, necessary to cause the spark, may be generated by a magneto driven by the engine, or by an induction coil.

Combustion may be started in an engine using paraffin by an electric spark. Or by the heat of compression, assisted by the heat of the hot bulb.

In a Diesel engine the fuel is first atomised and therefore enters the cylinder in the form of a finely divided spray. The particles of oil are vaporised by the high temperature of the air compressed in the cylinder, the oil vapour mixes with the air and combustion starts.

4.—What are the usual compression pressures in light oil engines, medium oil engines, Diesel engines ?

Ans.—Light oil engines from 50 lb. per sq. inch to 100 lb.
Medium oil engines about 150 lb. per sq. inch.
Diesel engines 480 to 500 lb. per sq. inch.

5.—Describe the four-stroke cycle of a Diesel engine.

6.—Explain how the two-stroke Diesel engine operates.

7.—Explain what is meant by the constant volume cycle, and by the constant pressure cycle.

8.—What is the thermal efficiency of a Diesel engine ?

Ans.—From about 30 per cent. to 35 per cent. calculated on the Brake Horse Power ; or from 40 per cent. to 45 per cent. estimated on the Indicated Horse Power.

9.—What are the approximate fuel consumptions per B.H.P. of a Diesel engine, at full, half and quarter loads ?—

Ans.—Full load about 0·4 lb.
Half load about 0·45 lb.
Quarter load about 0·55 lb.

10.—Why does the fuel consumption per B.H.P. increase at the lower powers ?

Ans.—The mechanical efficiency of an engine is the ratio $\frac{\text{B.H.P.}}{\text{I.H.P.}}$

The difference between the I.H.P. and the B.H.P. represents the work done by the engine in overcoming friction and driving auxiliaries. This difference is about constant at all power outputs. The mechanical efficiency therefore decreases as the power output decreases and the fuel consumption per B.H.P. must increase.

11.—What is a semi-Diesel engine ?

12.—How is a semi-Diesel engine started and reversed ?

Ans.—The fuel pipe lines are first primed, i.e., filled with oil by means of a small hand pump. The bulb is heated to a dull red by a blow lamp and the initial start is made by turning by hand, or in large engines by admitting compressed air into the cylinder. Refer to text for method of reversal.

13.—What is the average fuel consumption of a semi-Diesel engine ?

Ans.—About 0·52 lb. per B.H.P. per hour.

14.—What materials are used for inlet and for exhaust valves ?

Ans.—Inlet valves are made of a special steel. Exhaust valves may be made of similar material; or the spindle may be of steel and the head of cast iron, screwed on.

15.—What would be the effect of a leaky inlet valve ?

Ans.—Compression would be affected and the final temperature of the compressed air reduced, so that the engine might misfire, or combustion would be incomplete.

16.—What are pistons made of ?

Ans.—Good quality cast iron generally, but in some types of Diesel engines the piston head is made of cast steel.

17.—What are the average outlet temperatures of the cooling water ?

Ans.—100° F. to 120° F. when sea water is used.
140° F. to 180° F. when fresh water is used.

18.—What is the function of the scavenge pump ?

19.—Why is the air compressed in two or more stages in an air compressor ?

Ans.—By compressing in stages and cooling the air between each stage of compression less work is done because the compression approximates to isothermal conditions. Also the air never attains a dangerous high temperature.

20.—What material is used for air compressor coils, and why ?

Ans.—Copper is employed, since it is a good conductor of heat.

21.—What advantage is claimed for airless injection over blast injection ?

Ans.—No injection air compressor is required.

22.—Briefly describe the opposed piston engine.

Ans.—It consists of a cylinder open at each end and containing two pistons. The lower one is connected to a crank by means of a piston rod and connecting rod. The piston rod of the upper piston is attached to a crosshead beam from which side rods and side connecting rods lead to two additional cranks, one on each side of the crank worked by the lower piston. The two outer cranks are set diametrically opposite the centre crank. Both pistons approach the middle of the cylinder together on the compression stroke, and when the fuel is injected both pistons are forced outwards. This engine is a two-stroke engine.

23.—What are the advantages of this engine ?

Ans.—(a) The reciprocating parts are better balanced.
(b) A higher mean effective pressure can be carried.
(c) Good scavenging of the cylinder is obtained.

24.—How is the scavenging effected ?

Ans. The scavenge ports are arranged around the lower end of the cylinder and the exhaust ports are around the upper end. Both sets of ports are opened by the pistons as they approach the outer limit of their travel. The scavenge air passes through the cylinder from the lower end to the upper end, and ensures thorough scavenging.

25.—What is a silencer ?

Ans.—A silencer is a chamber, usually cylindrical in shape, and containing baffle plates. It may be water cooled. It allows the exhaust gases to expand gradually and thus enter the atmosphere with reduced noise.

CHAPTER VIII.

1.—The daily coal consumption of a steamer is 32 tons for main engines and 4 tons for auxiliaries when steaming at 10 knots. Estimate the daily consumption of oil, after conversion to oil fuel burning, when steaming at 11 knots, assuming that the amount of oil required is two thirds that of coal. Ans. 31 tons.

2.—A vessel steaming at 12 knots burns 48 tons of fuel per day. Calculate at what speed she should travel in order to do 3,120 miles when there are 50C tons of fuel in the bunkers and allowing for arrival in port with 70 tons in hand. Ans. 10·91 knots.

3.—A ship burns 44 tons of coal per day when her speed is 11 knots. How much coal will be burned on a voyage of 3,960 miles at a speed of 10 knots ? Ans. 545½ tons.

4.—The daily consumption of fuel of a ship travelling at 12 knots is 30 tons. Estimate how much fuel would be saved over a voyage of 2,480 miles if her speed is kept at 10 knots. Ans. 78·9 tons.

5.—A ship sets out on a voyages of 5,280 miles with 750 tons of fuel on board. She proceeds at a speed of 12 knots, the daily consumption of fuel being 30 tons, but after 10 days, 200 tons of fuel is accidently pumped overboard. Find the speed at which she should complete the voyage in order to arrive with 50 tons in hand.

Ans. 10·72 knots.

6.—A steamer burns 30 tons of fuel per day when travelling at 12 knots. What should be her speed in order to do 1,600 miles on 150 tons ? Ans. 11·39 knots

7.—A vessel begins a voyage of 5,530 miles at 12 knots burning 28 tons of fuel per day. After 6 days at sea the total fuel in the bunkers is measured to be 900 tons. What is the maximum speed at which she can complete the voyage so as to arrive with 70 tons of fuel in hand ? When will she reach port at this maximum speed ? Ans. 17·98 knots ; 8 days 19·4 hours.

8.—If 100 tons of fuel are consumed in a ship on a voyage of 800 miles at a speed of 10 knots, how far could she travel on 220 tons of fuel at a speed of 12 knots ? Ans. 1,222 miles.

9.—A vessel of 10,000 tons displacement burns 25 tons of fuel per day when steaming at 12 knots. What would be the probable consumption over a voyage of 3,000 miles when her displacement is 11,000 tons at a speed of 11 knots ? Ans. 233·2 tons.

10.—A ship commences a voyage of 3,864 miles at a speed of 12 knots and with 470 tons of fuel in the bunkers, burning fuel at the rate of 24 tons per day. After 3 days steaming she receives an S.O.S. and increases speed to 15 knots, but after travelling at this increased speed for 3 days, a message is received indicating that her assistance was no longer required. It is estimated that the diversion from her course added 68 miles to her voyage, calculate at what speed she should now run so as to arrive in port with 67 tons of fuel in hand.

Ans. 12·86 knots.

11.—If the I.H.P. developed by a ship's main engine was 3,000 when her speed was 10 knots, estimate the probable I.H.P. when the speed is 12 knots. Ans. 5184 I.H.P.

12.—The pitch of a propeller is 18 ft. 6 ins. What will be the difference in the ship's speed, in knots, if the engines are slowed down from 72 to 60 revs. per min. Ans. 2·2 knots.

13.—A ship travels a distance of 3,060 miles in 10 days 12 hours and the mean speed of the engines is 72 revs. per min. If the pitch of the propeller is 18 feet, find the average percentage slip. Ans. 5%.

14.—A ship's engine indicator registers 90,600 revolutions in one day. If the pitch of the propeller is 14 feet, estimate the day's run assuming a slip of 9%. Ans. 190 miles.